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Why Markets Make Mistakes

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Abstract

Many models of markets are based on assumptions of rationality, transparency, efficiency, and homogeneity in various combinations. They assume, at least implicitly, that decision makers understand the structure of the market and how it produces the dynamics which can be observed or might potentially occur. Are these models acceptable simplifications, or can they be seriously misleading? The research described in this article explains why markets routinely and repeatedly make "mistakes" that are inconsistent with the simplifying assumptions. System Dynamics models are used to show how misestimating demand growth, allowing financial discipline to lapse, unrealistic business planning, and misperception of technology trajectories can produce disastrously wrong business decisions. The undesirable outcomes could include vicious cycles of investment and profitability, market bubbles, accelerated commoditization, excessive investment in dead-end technologies, giving up on a product that becomes a huge success, waiting too long to reinvent legacy companies, and changes in market leadership. The article illuminates the effects of bounded rationality, imperfect information, and fragmentation of decision making. Decision makers rely on simple mental models which have serious limitations. They become increasingly deficient as problems grow more complex, as the environment changes more rapidly, and as the number of decision makers increases. The amplification and tipping dynamics typical of highly coupled systems, for example, bandwagon, network, and lemming effects, are not anticipated. Examples are drawn from airlines, telecommunications, IT, aerospace, energy, and media. The key conclusions in this article are about the critical roles of behavioral factors in the evolution of markets.

Introduction

Research into a wide range of markets at different stages of maturity and liberalization, e.g., airlines, telecommunications, energy, steel, shipping, aircraft, IT, media, and pharmaceuticals, has revealed recurring patterns of dysfunctional, counter-productive behavior (Weil 1996; Weil and Stoughton 1998; Stoughton 2000; Auh 2003; Ngai 2005; Dattée 2006; Sgouridis 2007; Weil 2007). The most significant behaviors are misestimating demand growth, allowing financial discipline to lapse, totally unrealistic business planning, and misperception of technology trajectories.

The research described in this article calls into question the assumptions of rationality, transparency, efficiency, and homogeneity on which many models of markets are based (see for example Samuelson 1948; Bass 1969; Fisher and Pry 1971, Malkiel 1973). The classic models assume, at least implicitly, that decision makers understand the structure of the market and how it produces the dynamics which can be observed or might potentially occur. Are these models acceptable simplifications, or can they be seriously misleading?

This article explains why markets routinely and repeatedly make “mistakes” that are inconsistent with the simplifying assumptions and often produce disastrously wrong business decisions. The undesirable outcomes could include vicious cycles of investment and profitability, market bubbles, accelerated commoditization, excessive investment in dead-end technologies, giving up on a product that becomes a huge success, waiting too long to reinvent legacy companies, and changes in market leadership. The article illuminates the effects of bounded rationality, imperfect information, fragmentation of decision making, and extrapolating past trends.

The Mistakes Markets Make

Misestimating Demand Growth

Misestimating demand growth usually is the result of inadequate understanding of how markets “work.” For example, the U.S. airlines did not recognize the transient effects of deregulation. Deregulation brought many new entrants into the market with lower costs and more aggressive, market-oriented management cultures. A significant decline in real fares and expansion of flights stimulated a transient surge in demand. For a period of 5-8 years, demand growth was far above the average rate before deregulation. But this rapid growth was not sustained, and more recently demand in the U.S. grew at a rate in between the two extremes.

In addition, the airlines did not appear to understand how markets change as they mature. As air transportation markets mature, the price elasticities increase steadily. This reflects the predominance of discretionary, highly price-sensitive, non-business demand, e.g., tourism, visiting friends and family, in more mature markets. Business travelers become more cost-sensitive, too. And as markets mature, the GDP and flight frequency elasticities decline, as does the strength of any self-reinforcing “experience effect.” A maturing market is one where base demand is saturating, but discretionary demand can continue to grow in response to declining fares.

The consequences of over-estimating demand growth are shown in Figure 1 (Weil 1996; Weil and Stoughton 1998). Imagine a situation where demand growth accelerates. The higher rate of growth is projected in to the future, leading to greater desired capacity and increased aircraft orders. As the new capacity joins the fleet, load factors may well decline.

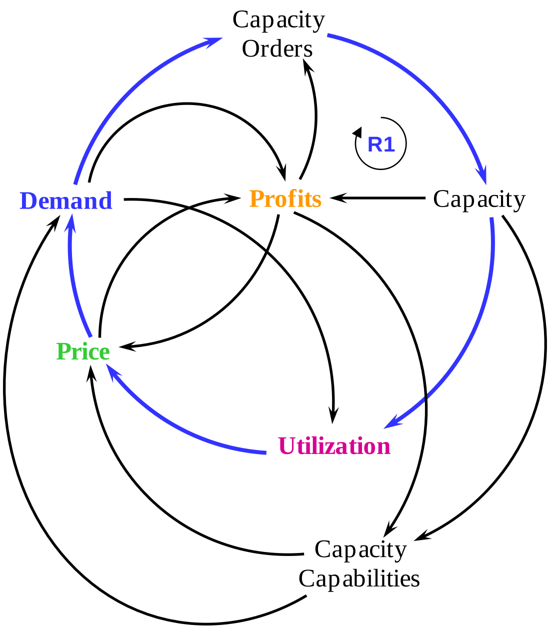

Figure 1: Over-Estimating Demand Growth

Lower load factors are almost certain if the acceleration of demand growth is transient, e.g., because of deregulation or an economic up-cycle. Load factors below target will lead to fare cutting which in turn will stimulate additional demand. This is a self-reinforcing "positive feedback loop" (highlighted as R1 in Figure 1). More capacity leads to increased demand; more demand, to increased capacity. Because of the long planning horizon and aircraft delivery times, excess capacity builds up in response to cyclical or surging growth in demand.

Planning errors are amplified by unusually long capacity delivery times. The capacity planning horizon of the airlines is extended when delivery times increase. Over-estimations of demand growth or market share, projected much farther into the future, cause even greater misjudgments of desired capacity. As shown in Figure 2, these relationships form another self-reinforcing positive feedback loop (R2).

A surge in aircraft orders (as in 1988-90) can cause delivery times to become substantially longer than normal. In response airlines extend their planning horizon, project higher demand and desired future capacity, and increase their aircraft orders. Unless manufacturer production rates respond proportionally, their order backlogs and deliver times will grow substantially. Here increased orders lead to longer planning horizons; and longer planning horizons, to further increases in orders.

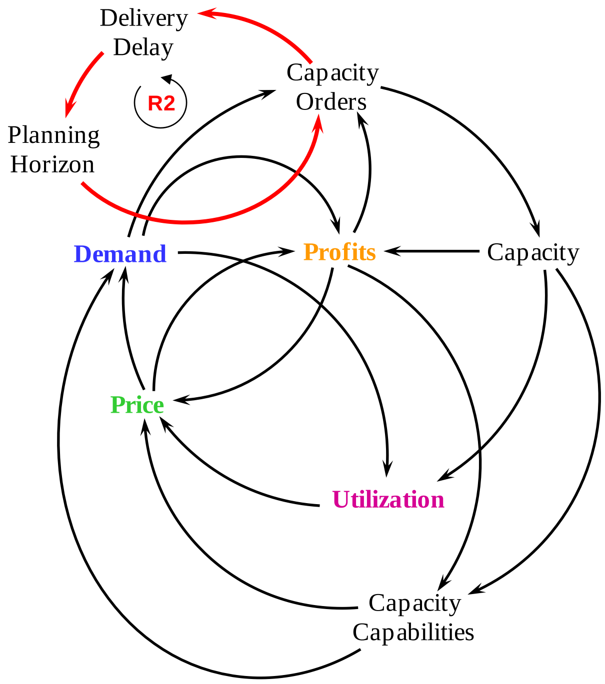

Figure 2: Amplification of Planning Errors

Allowing Financial Discipline to Lapse

The two positive feedback loops shown in Figures 1 and 2 reinforce each other and amplify the growth of excess capacity. The lapse of financial constraints within a market allows their perverse dynamics to go out of control. Traditional barriers to entry into the market and conservatism in decision making are eroded by freely available financing, e.g., from capital markets, financial institutions, leasing companies, and aircraft manufacturers. For a while, the airline industry was "hot." Entrepreneurs had no difficulty raising the capital to launch new airlines. New entrants ordered capacity in anticipation of building market share and, as described above, put market share growth ahead of short-term profitability.

When things turned bad for the industry, the normal industrial ecology did not apply. In the U.S., airlines are kept alive by the bankruptcy courts rather than going out of business. In other parts of the world, direct or indirect government subsidies have supported sick airlines. The leasing companies, desperate to place aircraft, have offered amazing deals. And the aircraft manufacturers, swamped with "white tails," became the financiers of last resort. Thus instead of a rapid shake-out of the industry and rationalization of capacity, new capacity continued to flow in.

Figure 3 indicates another important negative feedback loop through airline profitability. A wave of new capacity increases the airlines' expenses, reduces their profitability (for a time), and ordinarily would limit their access to financing and further capacity growth (loop B1). The lapse of financial constraints severely weakened this feedback. It has contributed very significantly to the growth and persistence of excess capacity.

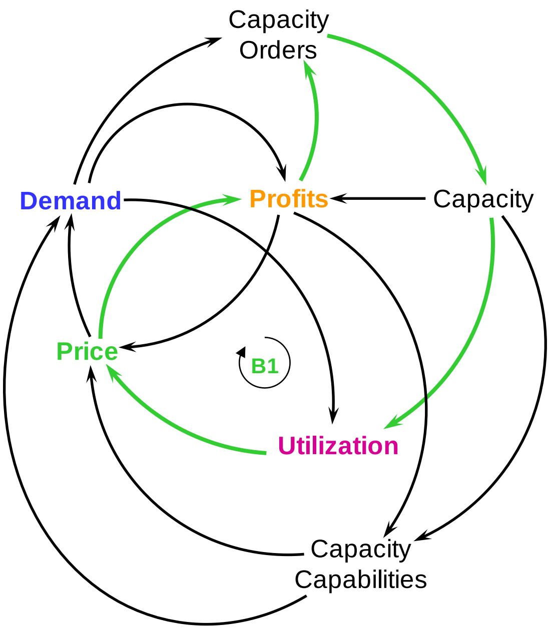

Figure 3: Laps of Financial Discipline

Market liberalization amplifies the dynamics described here by changing critical cause-effect relationships. Liberalization allows new competitors to enter a market with lower costs than the established incumbents. These may be start-ups or more efficient companies from other regions. They under-price the established competitors, and add capacity in anticipation of market share growth. For a period of time, they expect to operate with lower capacity utilization and to sacrifice profitability. Of course, the established players try to defend their position through more aggressive pricing, cost reduction campaigns, and also a willingness to sacrifice profitability.

The principal cause-effect relationships changed by market liberalization are summarized in Figure 4. The effect of capacity utilization on prices is stronger, and the effects of expenses and profitability are weaker. Why? Because new entrants price relative to the established players (attempting to under-price them) rather than based on their own costs. And because all competitors are more willing to sacrifice profitability as part of their offensive and defensive strategies. The expense drivers themselves are changed by the entry of lower cost competitors and the cost-cutting efforts of the established incumbents. This is captured by the links to expenses from demand and capacity. And as noted before, the effect of profitability on capacity orders is reduced.

The initial effect of market liberalization was to de-stabilize the airline industry. The negative feedback structure that controls capacity growth is weakened, and excess capacity is almost inevitable. What happens next depends on the barriers to exit. If the normal industrial ecology is allowed to work, there will be a shake-out and consolidation of the industry along with rationalization of capacity. In the mid-term, it is possible for an oligopoly to emerge and for the market to go through an extended period of stability. If, however, the ecological solution is impeded by institutional barriers and governmental support excess capacity will persist indefinitely and the market will steadily commoditize.

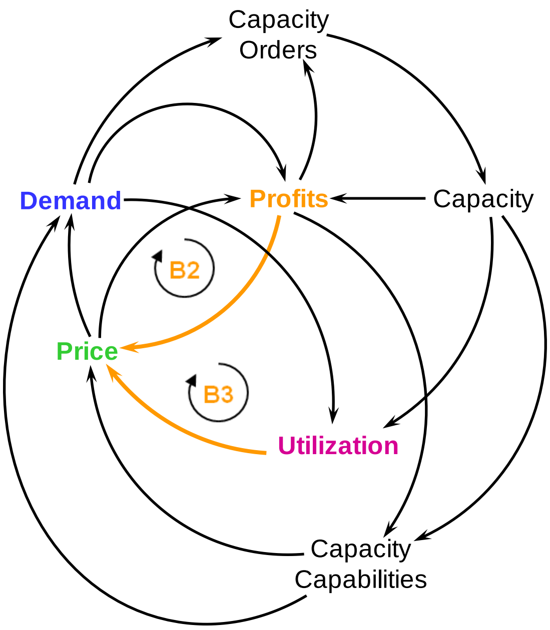

Figure 4: Effects of Market Liberalization

Unrealistic Business Planning

The business plans of new market entrants often are highly optimistic, if not completely unrealistic. This "success-oriented" bias may be necessary to win approval of the plan in a large established organization or secure funding for a start-up. One sees the same J-curve over and over again: lose money for the first three years while building a customer base; breakeven in year four; and achieve cumulative profitability in year five or six. It doesn't seem to matter if the business in question is a low-cost airline, broadband operator, producer of biofuels, or "web 2.0" social network.

The proliferation of players with unrealistic business plans further weakens the control mechanisms shown in Figures 3 and 4. Specifically, more competitors in a market means more independent decision makers engaged in projecting demand, planning and ordering capacity, and setting prices. The opportunities for misjudgments are increased. In addition, the proliferation of competitors almost inevitably leads to a situation where their market share aspirations cumulate to far above 100% of the market. New entrants start with nothing and expect to build market share. The established companies, however, are not prepared to concede share to the same extent. Market share objectives can cumulate to 150% or more of the actual market under such circumstances.

Another version of this phenomenon resulted from the growing prominence of aircraft leasing companies. The leasing companies aggressively increased their market share targets, well beyond the capacity that the airlines planned to obtain from them. In effect, they partially duplicated orders placed directly by the airlines. Aircraft ordering based on these overlapping objectives leads to substantial excess capacity.

The last effect is shown in Figure 3. The fare cutting that results from lower load factors has an adverse impact on yields, revenues, and airline profitability. Reduced profits, in turn, constrain aircraft orders. This is a self-correcting "negative feedback loop." Excess capacity reduces profits; poor profits reduce aircraft orders, thereby allowing demand growth to absorb excess capacity. The proliferation of competitors in a market weakens the feedback from profitability to orders, thereby increasing the likelihood of persistent excess capacity.

Misperception of Technology Trajectories

The classic models of technology substitution, e.g., Bass (Bass 1969) and Fisher Pry (Fisher and Pry 1971), simplify the complex underlying dynamics. The S-curve trajectories they produce have become iconic. They dominate the mental models and expectations of business executives, entrepreneurs, investors, and consumers. But recent research (Dattée 2006; Dattée and Weil 2007) clearly shows that the stylized S-curve is just one of many possible substitution trajectories. Under some circumstances the classic models are not acceptable simplifications. They can be seriously misleading. It is essential to recognize that the substitution trajectory matters. Assuming it always will follow the stylized S-curve can produce disastrously wrong business decisions.

The risks of planning errors is particularly high when the substitution trajectory is not a smooth, continuous S-curve, e.g., the "last gasp" scenario where a surge of improvements in the traditional technology postpones its replacement (a typology of technology substitution scenarios is described in Dattée 2006). The highly refined clipper ship which extended the age of sail by several decades is an example of this scenario. It would have been easy during the period 1850-70 for proponents of steam vessels first to overestimate the demand for the new technology and invest in excess capacity, then to underestimate demand and behave too cautiously. The "intermediate hybrid" (motorized sailing ships, film cameras loaded with electronics) and "pathfinder" (citizen's band radio, the Apple Newton) trajectories pose comparable risks.

The "double-shift" scenario is even more dangerous. Here the substitution trajectory of technology N+1 is cut short be the emergence of subsequent generation of technology. The initial penetration of technology N+1 is highly misleading. It can create a frothy, exuberant environment, leading to massive over-investment in the skipped generation.

An extreme example of this scenario may well be occurring in wireless communications. Five years ago there was great excitement about 3G mobile services (primarily based on WCDMA and CDMA2000 technology). They offered the prospect of the "mobile Internet" including m-commerce and rich media. Operators paid billions of dollars for 3G licenses which required additional billions of investment in new infrastructure. Penetration of 3G services has been slow. Now WiFi (802.11__ and its successors) and WiMax are threatening to disrupt the penetration of 3G and commoditize these services.

For years the major mobile operators were dismissive of WiFi. They said it was inferior to 2.5G and 3G mobile because of poor security, limited range, congestion problems, and of course no mobility. It was something for PCs, not phones; for geeks, not most people. Then Research in Motion, Nokia, Apple, and other suppliers offered WiFi enabled handsets, and the fight was on. The economics of WiFi and WiMax are highly favorable. A large city can be covered for a small fraction of the cost of 3G mobile, and the cost of turning a store into a WiFi "hotspot" is trivial. Since a large percentage of wireless calls are initiated within buildings, who needs mobile except as a backup when WiFi is not available?

WiFi is a disruptive technology from an adjacent market. It has a very different architecture from 3G and could easily capture a significant fraction of wireless communications. WiFi doesn't need a big market share or sustainable financial model to be devastatingly disruptive. Spoilers can do irreversible damage.

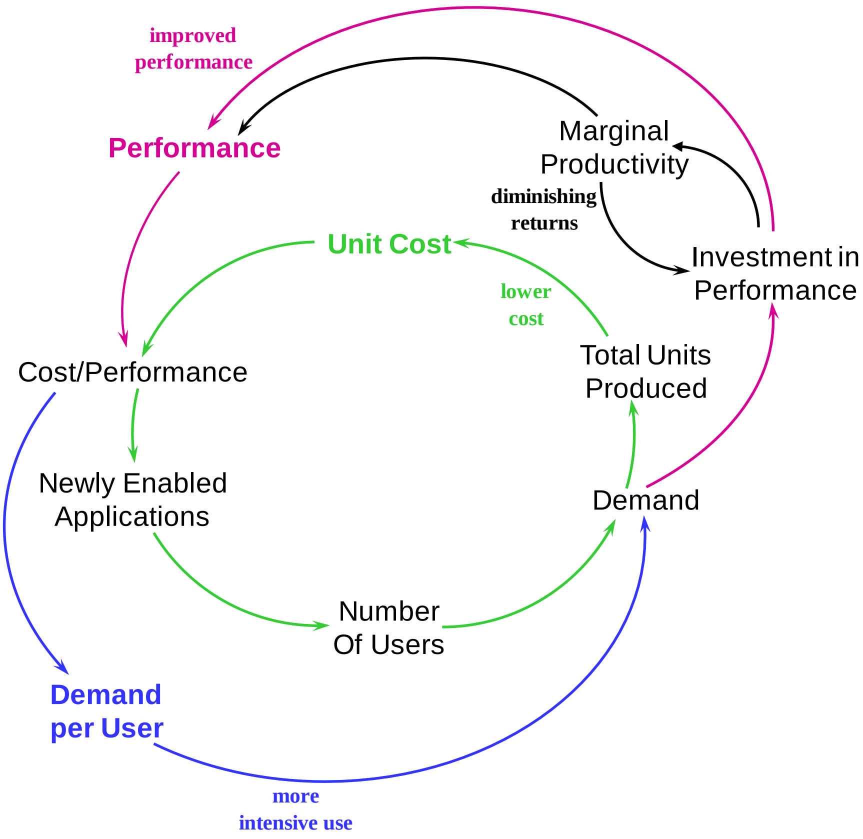

Figure 5: WiFi and 3G Mobile

The key dynamics of a generations of technology are presented in Figure 5. Imagine these dynamics applying WiFi/WiMax. As demand for WiFi services grows the total number of handsets and routers produced also increases. Their unit cost declines because of learning curve effects and economies of scale. Improved cost/performance enables new applications which increase the number of users and thus demand. Improvements in cost/performance also drives more demand per user. Growing demand stimulates investments in performance improvements, which feedback through both the number of users and intensity of use. However diminishing returns set in at some point, reducing the marginal productivity of these investments and ultimately constraining them.

Now imagine these dynamics applying simultaneously to 3G and WiFi/WiMax. The reinforcing dynamics are much stronger for WiFi and WiMax than 3G. The cost drops faster, performance improves faster, and intensity of use grows faster. WiFi threatens to disrupt and commoditize 3G. If this scenario occurs investment in 3G licenses and infrastructure will turn out to be an enormous destruction of shareholder value.

Why do These Mistakes Happen

Bounded Rationality

Some authors frame these issues in terms of bounded rationality (for example, Simon 1957; Forrester 1961; Morecroft 1985; Sterman 2000; Sterman et al 2007). This principle recognizes that decision makers rely on simple mental models which have serious limitations. They become increasingly deficient as problems grow more complex, as the environment changes more rapidly, and as more people must participate in key decisions "...agents make decisions using routines and heuristics because the complexity of the environment exceeds their ability to optimize even with respect to the limited information available to them" (Sterman et al 2007, p. 685).

Forrester in a pioneering article argued that failure to deal effectively with major social problems results from the intractability of complex non-linear feedback systems (Forrester 1973). "My basic theme is that the human mind is not adapted to interpreting how social systems behave. Our social systems belong to the class called multi-loop nonlinear feedback systems. Evolutionary processes have not given us the mental skill needed to interpret properly the dynamic behavior of the systems of which we now have become a part." (Forrester 1973, pp.211-212).

While discussing problems of population growth, economic development, pollution, and resource shortages Forrester drew on his extensive research into the behavior of complex business systems. He explained that all decisions are taken based on models, primarily mental models, that mental models tend to be fuzzy and incomplete, and that usually there is a contradiction between the assumed structure and assumed consequences of mental models. Forrester concluded that the behavior of complex systems is counterintuitive. "In many instances it then emerges that the known policies describe a system that actually causes the troubles. In fact, a downward spiral develops in which the presumed solution makes the difficulty worse and thereby causes redoubling of the presumed solution" (Forrester 1973 pp. 215-16).

Drawing on organizational cybernetics and System Dynamics Schwaninger attributed these dysfunctional behaviors to inadequate organizational intelligence. "Every day, corporations suffering from 'organizational dementia' inflict disastrous blows upon their economic, social and ecological environments, despite the fact that their members are, on average, intelligent and capable of learning. This means that organizational intelligence cannot simply be equated with human intelligence" (Schwaninger 2006, p.7).

Classical models of technology diffusion are examples of bounded rationality. In the interest of conceptual and computational simplicity they do not account for important interdependencies and structural fundamentals. "Classical models make strong assumptions on the process of innovation diffusion by considering at least one of the following: that adoption is a one-step process, the potential market size is constant, there is no repeat purchase, there is a uniform probability of dyadic interactions between prior and potential adopters, or that the innovation itself does not change over the diffusion process." (Dattée and Weil 2009, p.4) This last assumption means that further developments in price and performance are ignored.

The model shown in Figure 6 (from Dattée, FitzPatrick, and Weil 2007) generates an asymmetrical life cycle where there is a sudden drop in the sales of the current technology when it is confronted by the take off of a new generation. This dynamic behavior is not replicated by classical analytical models of diffusion; yet historical data from different markets, e.g., multiple generations of DRAM, the transition from VHS to DVD, clearly corroborate this "substitutive drop."

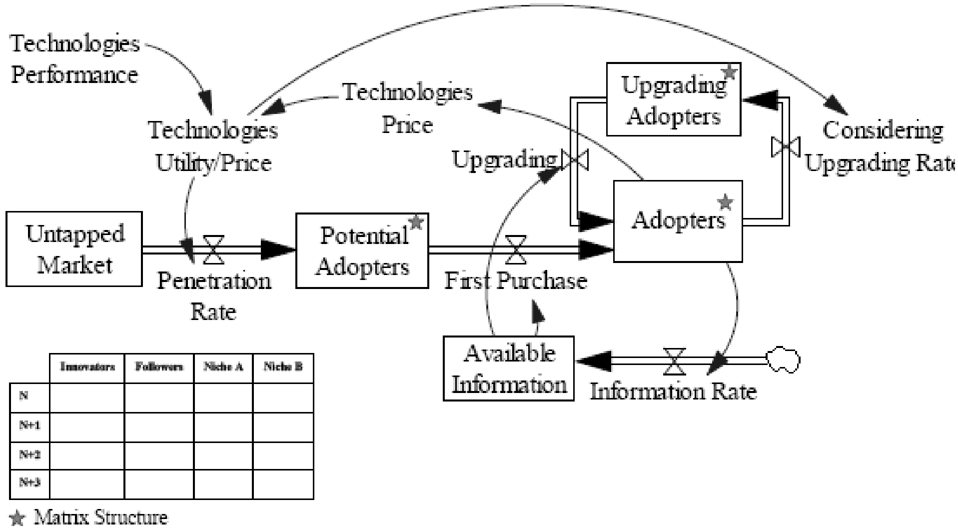

Figure 6: A System Dynamics Model of Technology Substitution

Another deviation from the stylized S-curve is the stair-step trajectory where penetration of a new technology evolves in a series of stages. This pattern, shown in Figure 7, reflects a highly heterogeneous segmentation of the market (Weil and Utterback, 2005). First, growth of the installed base overcomes initial skepticism and caution. Next, improvements in cost and performance enhance the appeal of products based on the new technology. Rising user requirements (influenced by increased marketing spend) add momentum to the substitution dynamics.

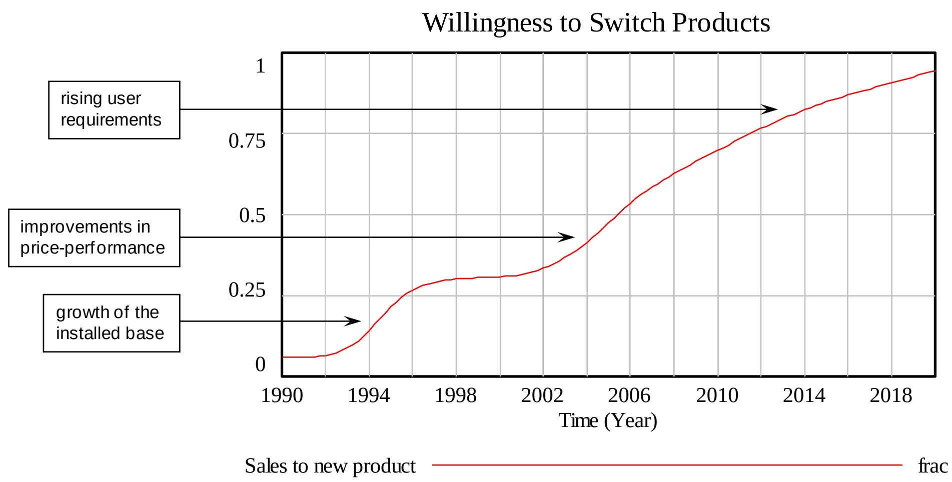

Figure 7: The Stair-Step Trajectory

An example is digital cameras. Many early adopters were professional photographers who used digital cameras to set up composition, lighting, and exposure before taking the picture with a “real camera.” Penetration accelerated as the resolution of digital cameras improved, they became smaller and easier to use, and the price declined. Further penetration is being driven by new requirements that are very difficult or impossible for film cameras to meet, e.g., posting pictures on Internet social networks.

Confusing Cause and Effect

The research described in this article raises significant questions about cause and effect. Commoditized industries generally are characterized by mature technologies and little innovation. But is this the consequence of commoditization? Does commoditization erode and eventually destroy the incentives and capabilities to innovate? Or is commoditization the result of inadequate investment in technology and innovation?

The same questions can be asked about the high proportion of fixed costs in most commoditized industries. Does this cause commoditization by exaggerating the difference between marginal and average cost? Or is it the effect of pursuing economies of scale in a market with razor thin margins?

The research shows that these factors are both causes and effects of commoditization. The same is true for the tendency in commoditized industries to add capacity in ever larger blocks, and for there to be inadequate supplier capacity and hence exaggerated lead times during each up-cycle in capital investment.

Technological progress is very important in mitigating commoditization. New technologies offer possibilities for differentiation, for example, supersonic travel, wireless Internet access, less-polluting fuels, fully integrated financial services. Technology-driven enhancements in product and service capabilities can stimulate faster demand growth. Consider the impact of the Internet on demand for telecommunication services. Less-polluting fuels may prevent regulatory constraints on energy consumption. And more rapid demand growth absorbs excess capacity more quickly.

In addition significant new technology can reward aggressive investors with a combination of lower costs, lower capital intensity, higher value added, and greater operating flexibility than their less aggressive competitors. This is particularly apparent in the telecommunications industry. By comparison the petroleum refiners are very cautious exploiters of new technology. The results raise a provocative conclusion. Commoditization easily can be a state of mind. In that case it inevitably becomes a self-fulfilling prophesy!

Extrapolating Past Trends

Demand growth in commoditized markets tends to follow an irregular "stair step" pattern, driven by the combination of recurring waves of over capacity and price cutting and macro-economic cycles. Demand growth typically slows as an industry matures. “This is both a cause and result of commoditization. A point is reached where eroding margins produce pressures which counter-balance the downward effects of poor capacity utilization on price. Ambitious new entrants seeking to build share, established companies defending their positions, and even governments backing national champions all have their limits. The result is to moderate price cutting and thereby slow subsequent demand growth" (Weil and Stoughton 1998 p.39).

Figure 8 is output from a simulation model of the US airline market (Weil 1996, Weil and Stoughton 1998). This simulation and the results shown in Figures 9 and 10 were run in 1997. Demand growth is quite irregular, showing the distinctive "stair step" pattern. Demand (expressed in revenue passenger kilometers or "RPK"/year) is essentially flat during 1999-2004 and again in 2009-11.

The average growth rate slows significantly. It is much higher during 1985-96, i.e., 3.4% p.a., than from 1997 to 2015, i.e., 1.9% p.a. Demand growth surges in 1994, driven by strong economic conditions and in addition the market's reaction to declining fares during 1995-96. Then demand growth peaks in 1997 and cycles sharply downward. This reversal is caused by rising fares and an assumed economic down-cycle. A recession was assumed in 2001-02 (which turned out to be correct).

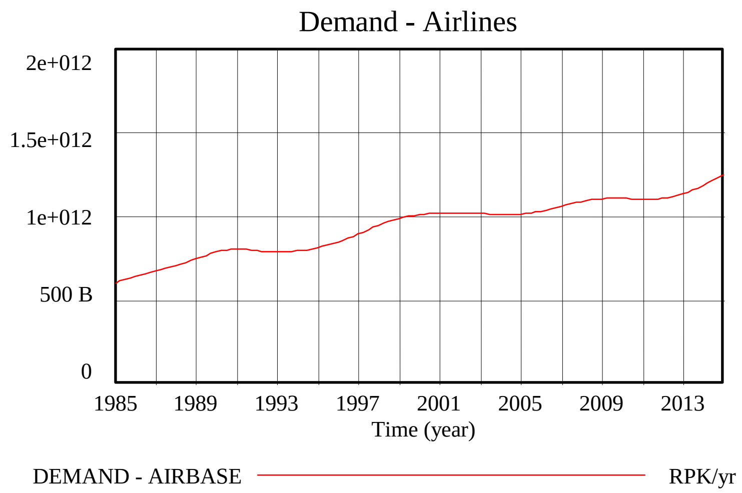

Figure 8: Demand – US Airline Market

In many markets including airlines, telecommunications, and energy demand forecasting appears to be based on the extrapolation of past trends. In a market with stair step demand growth this approach leads to systematic mis-estimation of demand and waves of excessive investment in capacity. These outcomes can be seen in Figures 9 and 10. Extrapolating the demand trend during 1995-99 would significantly over-estimate demand in 2000-05 (exactly what happened).

The peaks of capex in Figure 9 coincide with the end of a rapid growth phase in Figure 8, i.e., 1990 and 1998. The underlying cause is evident in Figure 10, which is output from the same model applied to the US telecom market. Projected demand is increasingly above actual demand, and the gap widens toward the end of each rapid growth phase, e.g., 1998-2000 (the dotcom bubble) and 2006-08.

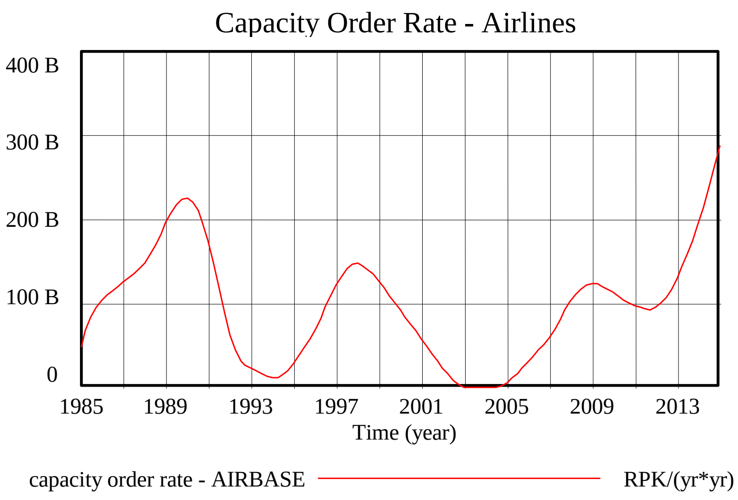

Figure 9: Capacity Orders – US Airline Market

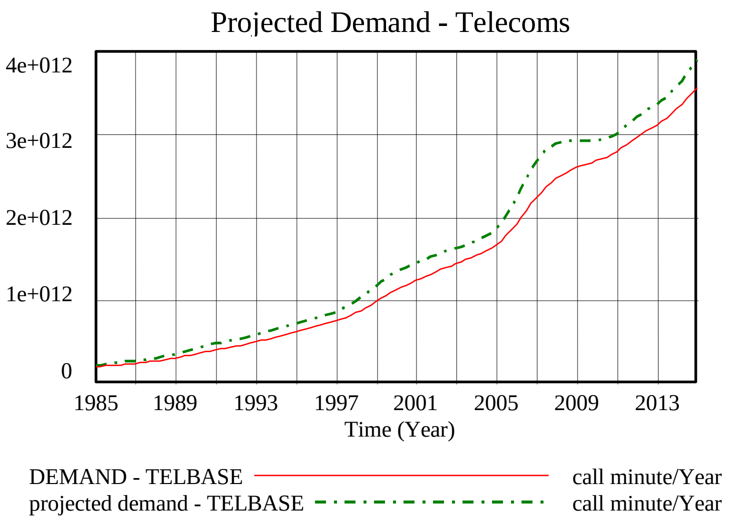

Figure 10: Demand and Projected Demand – US Telecom Market

In a landmark article Roberts highlighted the deficiencies of both “exploratory” and “normative” approaches to technological forecasting. Exploratory approaches attempt to predict the technological state of the art that will or might be in the future. Normative approaches are used to allocate resources to technology development activities and thus shape the future technology landscape.

Roberts explained, “Exploratory technological forecasting includes a variety of techniques for predicting the future of science and technology. Unfortunately most of the methods are really only variants on simple trend extrapolation procedures, broadly defined, that have limited utility in today’s rapidly shifting technological environment.” (Roberts 1978, p. 374).

Roberts cites many failures of trend extrapolation and argues that the S-curve model of technological progress is just a more mathematically sophisticated form of trend extrapolation. "This review of exploratory forecasting concluded that pathetically simply methods are being used to predict what technology will be in the future. The techniques paralleled an earlier stage of growth of economic forecasting and as yet have not recognized the importance of causal dynamic models" (Roberts 1978, p. 377). He observed the disconnect between the exploratory and normative approaches and used Figure 11 to show how the two are interrelated.

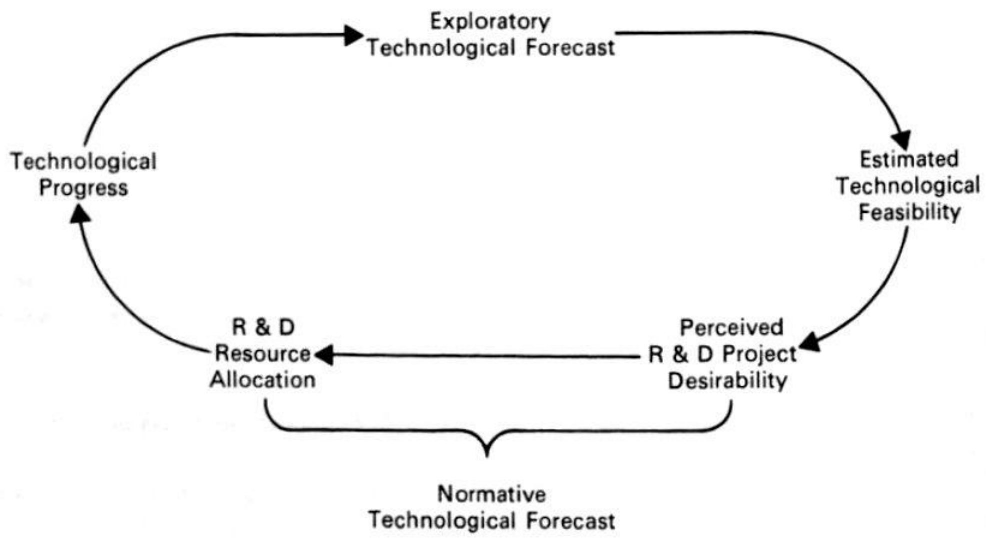

Figure 11: Exploratory and Normative Forecasting

Roberts' critique still is valid. The dynamic interaction between attempts to predict the future and resource allocation decisions determine how technological progress actually unfolds. Not understanding this connection has led to repeated mistakes on both fronts: completely underestimating the demand for personal computers and hybrid cars; massive over-investment in broadband data networks, 3G mobile licenses, and corn-based ethanol; dismissing disruptive innovations such as voice over IP, digital cameras, WiFi, user-generated media, and social networks; and being caught unprepared by the accelerated commoditization of information and communication technology infrastructure.

What are Their Consequences

Vicious Cycles

Capacity orders in commoditized markets tend to become increasingly cyclical over time, with the down-cycles becoming lower and more extended. This has profound implications for both the industries in question and their suppliers. Highly commoditized industries have periodic opportunities to introduce new technologies, but these are quite limited both in duration and relative to the installed base of capacity.

Suppliers face an increasingly severe "feast or famine" marketplace. They find it extremely difficult to maintain their production and technological capabilities during the periods of famine and to accurately anticipate the next feeding frenzy of orders. Thus suppliers are likely to become risk averse and reactive, waiting until the next cycle is clearly underway before expanding capacity and launching new development programs. In that case lengthy delivery delays, serious quality problems, and slowly evolving technology are the probable results. This is the situation currently facing major parts of the commercial aircraft industry.

"The combination of slowing demand growth, eroding profitability, and inherently long asset lifetimes (generally 20-30 years in the industries studied) leads to stagnation of the industry's portfolio of capacity. There are powerful incentives in a commoditized industry to stretch asset lives and invest as little as possible. Significant 'barriers to exit' which make it more difficult and/or costly to eliminate capacity (e.g., governmental support of national champions, protection by bankruptcy courts, or environmental regulations which impose large clean-up obligations) exacerbate those dynamics" (Weil 2007. p. 145).

The implication is quite clear: any new technologies are adopted very slowly. The outcome is a perverse technological lock-in. Technologies which offer the possibility of moderating or escaping from the commodity game have a small impact. The research indicates that this is a crucial part of the advanced stages of commoditization. Industries, at least in their traditional forms, become trapped in a commodity business from which escape is increasingly unlikely.

Market Bubbles

The entry of firms into a market and the subsequent exit of many or most competitors are central to the dynamics of innovation (Utterback 1994). In the early stage of a new market or generation of technology the perceived opportunity is large. No firm is dominant. The product or service is not highly refined and there are many competing variations. As the number of companies in the market grows so does the rate of experimentation and innovation.

The entry rate is determined by the expected growth and profitability of the market and availability of finance. In the early fluid stage of a new generation of technology the size of the prize is quite uncertain. Thus a "lemming effect" often occurs, where the inflow of entrants reinforces the impression that this must be the "new big thing," attracts a large amount of investment, and thus encourages additional firms to enter the market. In a relatively short time there can be a surprisingly large number of companies in the market. These self-reinforcing dynamics were conspicuous during the dotcom boom (Weil and Utterback 2005).

The perceived risks of a new technology can be high in the early stage. It is unproven, and potential users have reason to be skeptical and cautious. Things start to change as the number of users increases. The quantity and quality of information about the new technology improves, allowing more confident assessments and decisions. Highly respected reference users legitimize a new technology and make its selection much easier to defend. And products or services based on the new technology can become a fashionable "must have." This happens in business markets as well as consumer markets, e.g., the rush by companies in the late 1990s to get on-line. Then the risk is of not adopting, of being seen as "behind the times" or "not getting it."

Social factors, e.g., trust, fashion, lead users, perception and extrapolation of trends, information flows, bandwagon effects, and network effects, often play a major role in market bubbles. As described by Sterman (2000) bandwagon effects are driven by media coverage and positive word of mouth which create the perception of a hot product. Network effects involve a strong positive feedback loop. "As illustrated by the VCR industry, the utility of a product often depends on how many others are also using it" (Sterman 2000, p.370.). These factors are particularly significant in determining how a market responds to innovative technologies, products, and business models.

Apple's spectacularly successful iPod highlights the importance of social factors in innovation and technology adoption. Strong bandwagon and network effects reinforced the virtuous dynamics described by Weil and Utterback (2005). Network effects occur when the value of a product or service increases non-linearly with the number of users, e.g., e-mail, text messaging, and social networks. Bandwagon effects result from a fashion craze, something everyone must have. The combination both effects is very powerful. The iPod became a fashion craze.

Accelerated Commoditization

Innovative technology is quite vulnerable to commoditization. This term denotes a competitive environment in which product differentiation is difficult, customer loyalty and brand values are low, and sustainable advantage comes primarily from cost (and often quality) leadership.

Commoditization is driven by persistent excess capacity, which in turn is the result of over-estimation of demand, proliferation of competitors, easy availability of capital, pursuit of economies of scale, and barriers to exit (Weil, 1996; Weil, 2007). Commoditization causes the emergence of a mass market for products based on the new technology but ultimately squeezes R&D, leading to technological stagnation. Product cost-performance plateaus. Sales growth continues, but with little or no profit. Examples range from personal computers to digital media, wireless communications, and biologic drugs.

Mistaken assumptions about the substitution trajectory can trigger the dynamics of commoditization. Overestimation of mid-term demand often stimulates a wave of new market entrants with ambitious objectives and aggressive investment plans. When a new technology is "hot" it is easy for these companies to raise capital to finance investments in product development, production capacity, and infrastructure. Over-estimation of demand growth and the proliferation of competitors stimulates excessive investment. More competitors in a market means more independent decision makers. "The opportunities for misjudgments are increased." (Weil, 1996, p. 12)

Excess capacity stimulates intense price competition. Pipeline constraints often lead to long delays between capacity orders and when new capacity enters service, amplifying planning errors caused by extrapolation of past demand trends and over-optimism regarding the substitution trajectory. This accelerates the build-up of excess capacity, especially when there are significant barriers to exit.

Investment in Dead-End Technologies

Consider the situation discussed above where a new technology N+1 emerges while the current technology N is diffusing into the market. Figure 12 (from Dattée, FitzPatrick, and Weil 2007) shows that a simulation of these dynamics creates a large pre-emption effect by technology N+1 and this clearly results in what Dattée and Weil call a "substitutive drop" in the sales of N. If unforeseen, this could have a devastating effect on the return on investments in technology N. Indeed, one can see in Figure 12 "that by using the data up to the discontinuity point, a classical Bass model can be satisfactorily fitted to the life cycle of technology N. However, it would completely miss the substitutive drop." (Dattée and Weil 2009, p.27) Any further investment in technology N based on this expected profile could be a serious mistake.

"To overcome this structural mismatch, classical diffusion models are calibrated a posteriori with a smaller market size parameter and they anticipate the peak of sales as shown in figure 12c (Dattée, FitzPatrick, and Weil 2007, p.13). This behavior is extremely clear in the application of Norton and Bass' multi-generations model to DRAM devices (Norton 1986, Norton and Bass 1987, figure 2).

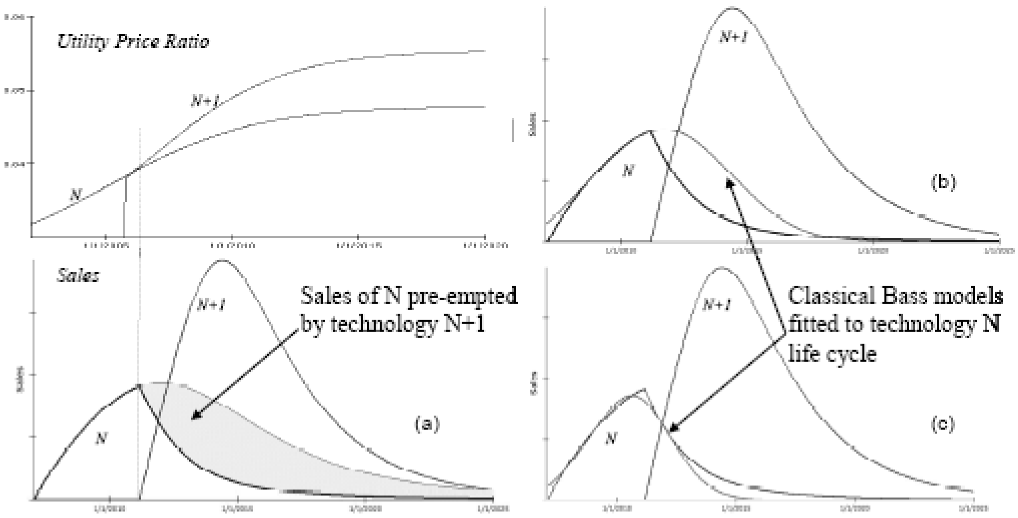

Figure 12: The Substitutive Drop

Giving Up Too Soon

Another example of "stair step" demand growth is the mature market for very expensive, long-lived assets such as military transport aircraft (Weil, 2004). The conventional wisdom says these markets are lacking in opportunity, particularly for new entrants or new products, because their growth is quite slow, asset lives are long, operators have strong incentives to stretch the life of existing assets rather than replace them, and the markets are dominated by a small number of well entrenched suppliers. Innovative technology can disrupt a mature market and change its dynamics.

Decision makers must contend with important tradeoffs. Be an early buyer of the new model, or wait and see? Replace old aircraft at the normal rate, at an accelerated rate, or stretch their operational life until some of the uncertainties are resolved? Select a new aircraft which better meets mission requirements and promises superior cost/performance, or play it safe with the well established old models? The psychology of the market is critical in shaping these tradeoffs and decisions.

User confidence is driven by a potentially powerful reinforcing loop. The more that operators select the new model, the larger the number of theses aircraft in the global fleet. Seeing the aircraft in operation builds confidence. The mission effectiveness and cost/performance can be verified. Early adopters are reassuring, especially if they are high prestige "reference users." For example, decision makers in Japan would find it much easier to justify selecting the new aircraft if the US or Germany had already done so and were very satisfied with its technology, performance, and economics.

Several other dynamics can come into play as the new aircraft penetrates the world fleet. With most complex manufactured products there is a significant decline in unit cost as production grows. Lower costs result from both learning curve effects and economies of scale. Lower unit costs means a better cost/performance ratio for the new aircraft. That will accelerate the obsolescence of older aircraft and increase the incentives and pressures to replace them with the new model.

As more of the new aircraft enter service user expectations can change. They begin to take for granted its greater capabilities, which then become the norm. Increased user expectations drive growth of their mission requirements, e.g., range, payload, flexibility, landing/takeoff conditions, and survivability. Indeed the new model may enable entirely new missions. Powerful tipping dynamics build momentum. The network effects, economies of scale, and user expectations and requirements are all driving the market in favor of the new model. The result is accelerated replacement of old aircraft.

The likely scenario in this case is summarized in Figure 13: several waves of orders for the new aircraft separated by long periods of little or no further penetration. The initial orders from launch customers are followed by a slow period where there is considerable interest in the new aircraft but few additional orders. At this stage other potential buyers take a "wait and see" approach. They lack sufficient confidence to select the new model.

Year 0-1	• Initial orders from launch customers
Year 7-8	• Second wave of orders
Year 10-11	• Third wave of orders
Year 12-14	• Accelerated replacement of old AC
Year 16	• Fleet stabilizes

Figure 13: An Example of the Stair-Step Trajectory

When the first aircraft are completed and delivered there is a tangible product to evaluate. The cost/performance promise can be validated and satisfied lead users can serve as reassuring precedents. After the new model enters service a second wave of orders occurs. As time passes the new aircraft is tested in action. Its innovative technology produces very impressive mission performance which further increases user confidence and leads to a third wave of orders.

This substitution trajectory has serious strategic implications for both proponents of the new technology and incumbents. There are very significant risks of misinterpreting the market dynamics and making major strategic errors during the early stages. The innovator may give up in frustration during the first slow period. It is easy for incumbent suppliers to be dismissive of the new technology. The slow period seems to confirm that it has failed to gain momentum in the marketplace. The dominant incumbents may feel confident and secure, and wait too long before taking the challenge seriously.

With the stair-step trajectory success or failure of the product based on innovative technology depends primarily on how the competitors behave. If the innovator avoids mistakes and the established suppliers are complacent and slow to react, the outcome is success for the new technology. If however the incumbents react quickly and effectively they can use their strength to exploit any missteps of the innovator and marginalize the new product. The tipping dynamics are strong and unforgiving.

Waiting Too Long to Reinvent

Misinterpreting the more complex substitution trajectories may delay attempts to reinvent legacy companies, strategies, and business models. As a company matures its capabilities become more and more deeply embedded in business processes, relationships, and values. The most likely result is what Sull calls “active inertia” (Sull, 1999). Companies fail because the capabilities that made them successful become sources of rigidity. This not only hampers their ability to innovate, but also channels their energy and activity in the wrong direction when faced with a major challenge.

Large, mature companies often lack the capabilities to be successful with a disruptive product or service innovation. Christensen and Overdorf observed that they lose the ability to enter small, emerging markets (Christensen and Orverdorf, 2000). Their values change and what once was an attractive opportunity now looks “not big enough to be interesting.” Established firms tend to dismiss a new technology as “inferior” by traditional metrics. Disruptive innovations create new markets with different value propositions. In order to succeed in these emerging markets organizations need new capabilities.

Henderson and Clark describe how “architectural innovations” destroy the capabilities of established firms (Henderson and Clark, 1990). Architectural knowledge is embedded in their structure and information processing procedures. The opportunities and threats posed by an innovation can be screened out by existing information filters. And the need to build and apply new architectural knowledge conflicts with what made the firm successful in the first place.

Technological evolution is composed of periods of experimentation followed by the acceptance of a dominant design. During the experimentation phase design exploration and assimilation of new knowledge are essential. New entrants have an advantage because they have fewer constraints.

The window of opportunity for creating new capabilities is limited. Research by Christensen, Suarez, and Utterback shows that firms that enter a market during the "window of learning" just prior to the emergence of the dominant design will be less likely to exit (Christensen, Suarez, and Utterback, 1998). In fast changing industries, rather than pure first mover advantage, there is a short window of opportunity before the emergence of a dominant design. The timing of learning becomes critical, because with rapid technological change knowledge and capabilities quickly obsolesce.

Munir and Phillips highlight how constraining the concept of "industry" becomes during a period of disruptive innovation (Munir and Phillips, 2002). It is an over-simplification which distorts critical perceptions and decisions and often leaves large, established companies surprised by changes in the competitive environment. They fail to understand who their key competitors are and how customer needs, expectations, and values have changed. They do not realize that their knowledge and capabilities are becoming obsolete. The most frequent outcome is a change in market leadership.

Conclusions

Models which assume, at least implicitly, that decision makers understand the structure of the market and how it produces the dynamics which can be observed or might potentially occur can be dangerous simplifications and seriously misleading. The research described in this article explains why markets routinely and repeatedly make "mistakes" that are inconsistent with the simplifying assumptions of rationality, transparency, efficiency, and homogeneity.

Decision makers rely on simple mental models which have serious limitations. They become increasingly deficient as problems grow more complex, as the environment changes more rapidly, and as the number of decision makers increases. The amplification and tipping dynamics typical of highly coupled systems, for example, bandwagon, network, and lemming effects, are not anticipated. Behavioral factors play critical roles in the evolution of markets.

Markets become increasingly commoditized as they mature. Commoditization is driven by persistent excess capacity, which in turn is the result of over-estimation of demand, proliferation of competitors, easy availability of capital, pursuit of economies of scale, and barriers to exit. As markets grow more commoditized the sources of sustainable advantage become less tangible, e.g., IP, know-how, information, brand, reputation, relationships, trust, and the "customer experience." (Weil and Weil 1999). Competing on intangibles requires quite different capabilities from competing on product or service price and performance.

Risk taking by both suppliers and customers has significant impacts on the evolution of markets and creation of value from innovations. The early stage is characterized by a frenzy of supply-side experimentation. Many different product or service variations and business models are tried. Multiple form factors and standards compete in the marketplace.

The willingness to experiment and ability to learn are critical success factors at this stage (these issues are discussed by Henderson and Clark 1990; Roberts and Liu 2001; Munir and Phillips 2002; and Christensen, Suarez, and Utterback 1998). When companies are faced with radical technological changes decision-making cannot be based on existing understandings of customer needs, values, and expectations.

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