Application of System Dynamics to Corporate Strategy: An Evolution of Issues and Frameworks

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Abstract

This paper discusses five landmark projects which highlighted issues and produced frameworks that became important building blocks in the application of System Dynamics to corporate strategy. The early models were primarily at the level of the firm. The first model described in the paper captures the tension among conflicting performance objectives and shows how the conflicts impact mid-term company performance. The second model represents the behavior of an R&D organization as it responds to changing pressures and direction from corporate management. Over time the focus shifted to market behavior and competition. The third model explains powerful long-term dynamics that lead to "commoditization" of products and services. Recent work analyzed the social dynamics of markets, e.g., as they affect innovation and technology substitution. The fourth model in the paper represents the fundamental dynamics of innovative industries, building on an extensive body of research and publications. The final model focuses on the market impacts of social factors, e.g., trust, fashion, the characteristics of lead users, how trends are perceived and extrapolated, the flow of information, bandwagon effects, and network effects. The progression started with classical Industrial Dynamics, models of the firm which focused on orders, production, and shipments. At each milestone more behavioral richness and complexity were recognized and represented. What do we know now that we did not know when the field was founded fifty years ago? The most important lessons are about the critical roles of organizational, social, and psychological factors in important business decisions, competitive behaviors, and the evolution of markets.

Introduction

This is a personal journey which began at MIT in the Fall Term of 1962 when, as an undergraduate, I enrolled in course 15.581 Industrial Dynamics I. Jay Forrester was the instructor, assisted by my future friend, colleague, and business partner Ed Roberts. The following year I was in the first cadre of Jay's innovative Undergraduate Systems Program. This was a two-year, largely self-directed program of management education based on Industrial Dynamics. Also in 1963 Ed Roberts and Jack Pugh founded Pugh-Roberts Associates. I started working at Pugh-Roberts in 1966 while in graduate school.

During the forty years which followed I have specialized in applying System Dynamics to corporate strategy. The early models were primarily at the level of the firm. Over time my work shifted to market behavior and competition. Most recently I have analyzed the social dynamics of markets, especially as they affect innovation and technology substitution. Looking back I can see a series of landmarks, projects which highlighted issues and produced frameworks that became important building blocks for me, my colleagues, and my students. On the fiftieth anniversary of the founding of our field I thought it would be useful to record them and discuss their significance.

Conflicting Objectives

One of my first consulting projects was with a large Canadian food manufacturer and retailer. It focused on the dynamic interactions of multiple conflicting performance objectives. "The opportunity for conflict among performance measures, and therefore the lack of clarity as to how the measures mold behavior, is probably greatest in vertically integrated companies. Not only do these firms offer the usual possibility of individual measures conflicting to some extent (e.g., sales and profits), but also the opportunity exists for interdivisional conflict as a result of the measurement process (e.g., the frequent outcome of applying the profit center concept)" (Roberts 1978, p.427).

The model represented the manufacturing, distribution, and sale of bakery goods. Most of the company's manufacturing investment was in this area. The model centered around two related flows: orders and goods, and cash. Orders to manufacturing were based on historical sales data, but were modified by pressures from senior management. Pressures to increase sales led to higher orders and pushing goods into the stores. Pressures to improve gross margins produced the opposite behavior. Orders were scaled back to minimize the sale at reduced prices of goods which had passed their "sell by" date. Manufacturing had the option to modify the orders from retail. In an attempt to increase its income contribution manufacturing frequently shipped 5-10% more than was ordered. It also could offer lower transfer prices to stimulate more sales.

Management's efforts to boost sales conflicted with its efforts to increase gross margin. To increase sales prices were cut and more goods pushed into the stores. To improve margin management would do the opposite. Analyses with the model showed that "...this conflict (and its resolution) is a critical determinant of how this part of the company performs" (Roberts 1978, p.425). The dynamic behavior of the business results from the interaction of four feedback loops shown in Figure 1.

Corrective actions regarding one performance objective, after a significant delay, causes a variance in one or more of the other objectives. For example, if sales fell below budget retail would reduce prices, spend more on advertising, and offer more specials (balancing loop B2). However none of these actions had an immediate impact. Indeed the variance easily could grow worse, stimulating even more aggressive corrective actions. Finally sales were back on track. However lower prices and over-ordering reduced gross margin(reinforcing loop R1 shown in dashed lines). Now a margin variance grabbed management's attention and the pressures and resulting behaviors reversed (loops B3 and R1).

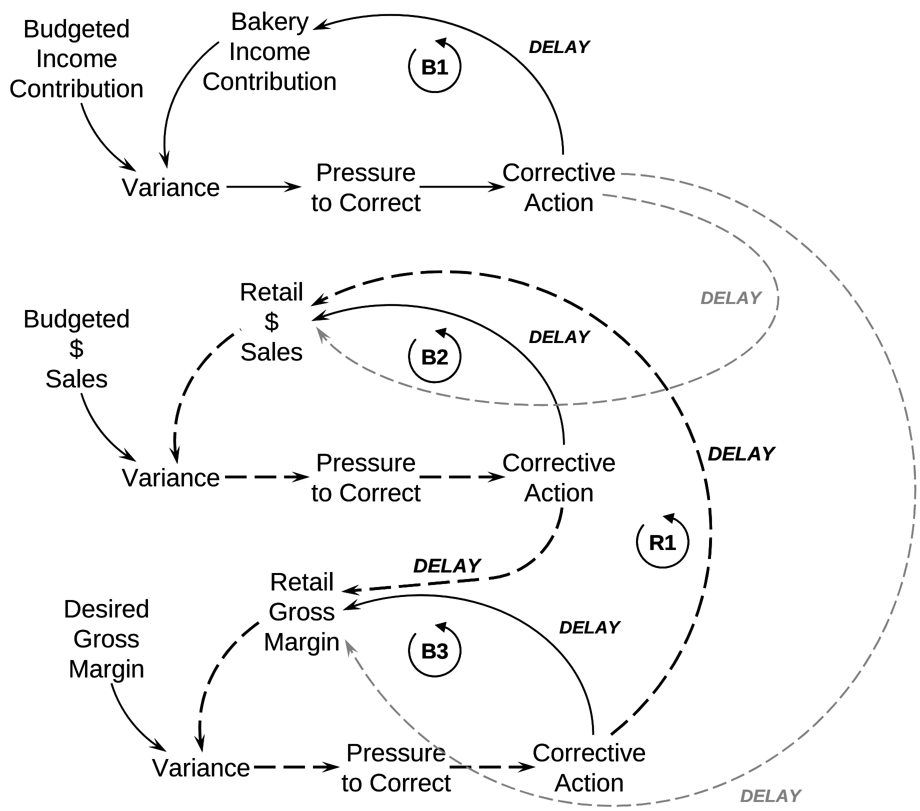

Figure 1: Conflicting Control Loops

Analyses showed that continual oscillations among conflicting performance objectives caused the company to fall short of all of its targets. The company wanted to grow faster than the overall market, but this only could be accomplished through aggressive pricing and advertising. That strategy would be possible if gross margin were ignored, but a margin variance could not be ignored indefinitely. Moreover the company could not sell more than it produced. Rapid growth required simultaneously stimulating demand and increasing output while maintaining a satisfactory margin, e.g., through economies of scale. It is a very difficult balance to achieve and sustain.

The need for alignment among strategic objectives and operating performance measures is a recurring theme in the literature. Hamel and Prahalad emphasized the critical role of a company's strategic intent, i.e., its vision of market leadership. "Strategic intent provides consistency to short-term action, while leaving room for reinterpretation as new opportunities emerge" (Hamel and Prahalad 1989, p.65).

Other authors frame the 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).

This model was developed in 1967. It captured the dynamic tension among conflicting performance objectives and showed how the conflicts impacted mid-term company performance. These issues were central in subsequent projects. The resulting model formulation became a key element of my solution repertoire and featured in many later models, e.g., my work on commoditization (Weil 1996; Weil and Stoughton 1998).

Resource Allocation

Five year later a project with a major IT systems supplier became another landmark. The project focused on R&D management at the strategic level. "Many important R&D strategy issues pertain to the policies which govern the acquisition and allocation of resources. The predominant resource in R&D organizations is people" (Roberts 1978, p.326). Resource acquisition and allocation decisions are intimately interwoven with aspects of technology strategy, e.g., the technical advancedness of the company's products, the mastery of the technologies used in products, the nature of new technology programs, and the priorities for assigning resources to various activities.

The model represented the dynamic behavior of the R&D organization as it responded to various pressures and direction from corporate management. It built on and extended the pioneering work of Roberts (Roberts 1964; Roberts 1967). The model consisted of five interrelated sectors: technology programs, new product exploration, product development programs, performance measurement and control, and human resources allocation. Innovations in technology enabled innovations in new product exploration and then in major development programs. "Thus technological advancements can have a cascading effect through the system, leading ultimately to the introduction of more advanced products in the market" (Roberts 1978, p.329).

This structure is shown in Figure 2. The distinguishing feature of the model is its focus on key characteristics of the company's technology base, R&D activities, and products in the market. Technology programs, new product exploration programs, and product development programs were described in terms of their "advancedness," i.e., how large a technological they represented relative to the previous generation. The advancedness of these activities compared to the company's level of technology "mastery," i.e., its depth of experience with the relevant technologies, determined the productivity of technical staff. The series of linked stocks and flows in Figure 2 represented the sequential inter-relationship of these characteristics.

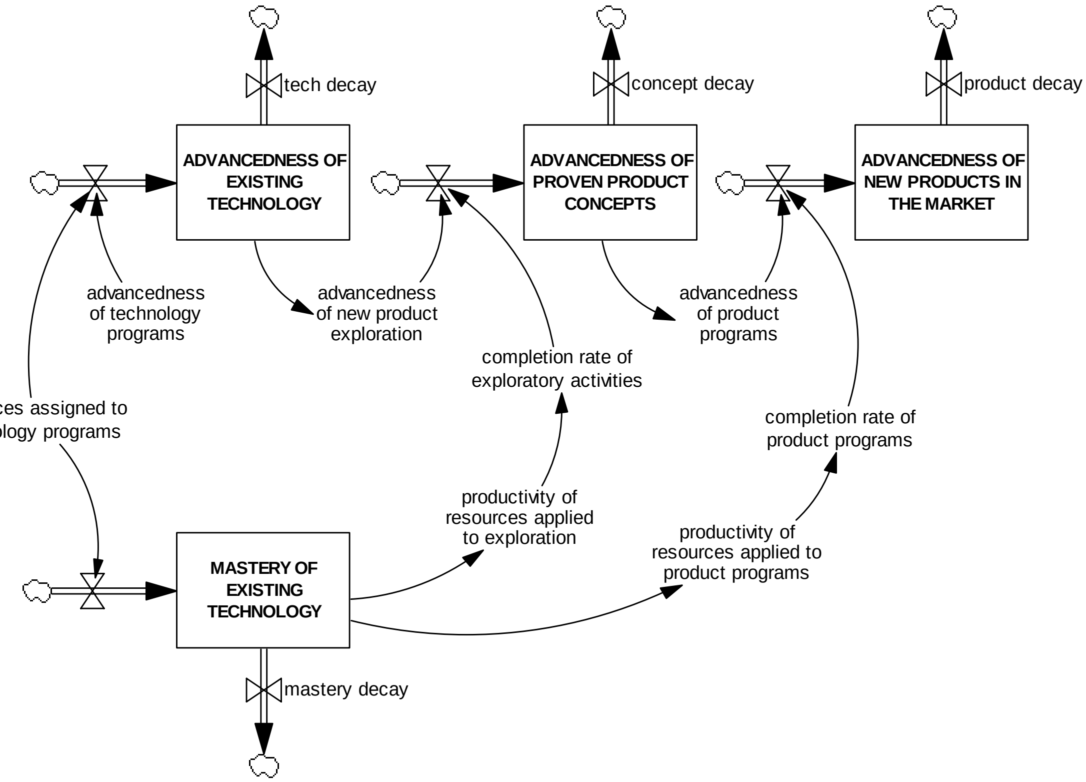

Figure 2: The Product Development Pipeline

The performance measurement and control sector dealt with the setting of performance objectives and responses to performance problems. It captured the trade-off between technical and schedule performance, the sequential interdependency of technical activities, and the impacts of technical problems on staff productivity. The resource allocation sector acquired and allocated two types of people, i.e., researchers and engineers, to six activities: product performance problems, major product programs, new product exploration, technology programs, technology idea nurturing, and product idea nurturing. Skills constraints and management policies limited possible reallocations.

Analyses highlighted the causes and implications of "workflow bunching," a common pattern of oscillating and mal-distributed workload experienced by many R&D organizations. The dynamics produce periodic bulges in workload at various stages of the R&D pipeline, shortages of new product candidates, waves of new products entering the market, insufficient mastery of new technologies, and unanticipated product performance problems. "Looking at the output of the R&D process, the result of workflow bunching appears as 'bursts' of product programs followed by 'lulls.' Within the R&D organization, it looks like a series of waves, surging down the product development pipeline" (Roberts 1978, p.337).

Workflow bunching is caused by the combination of dysfunctional resource management policies, over-optimistic commitments, and changing corporate-level pressures for diversification. Limiting growth in overall headcount and also allowing rapid reallocation from one technical activity to another amplify the problem. Over-optimistic commitments lead to initially unrecognized additional real workload. It is an even more powerful driver of workflow bunching, since more reallocations of resources are required. Changes in corporate priorities obsolete recent product exploration work and require the R&D organization to develop a new generation of product candidates under great schedule pressure.

These were fundamental concepts, not only in subsequent strategy applications of System Dynamics, but also in the project management models (for example, Cooper 1980; Abdel-Hamid and Madnick 1991; Weil and Dalton 1992; Lyneis, Cooper, and Els 2001) which became the specialty of Pugh-Roberts. Applications to project management illuminated the existence and critical impacts of “undiscovered rework,” i.e., work which was considered to be complete and correct but actually was not. When this rework was discovered later in the project, it represented unplanned workload which escalated costs, delayed completion, and put dysfunctional pressures on management. Repenning (2001) extended the concept to a multi-project development environment. He analyzed the impacts of fire fighting. “In the product development context, fire fighting describes the unplanned allocation of engineers and other resources to fix problems discovered late in a product's development cycle” (Repenning 2001, p.5).

This model expressed in the System Dynamics paradigm concepts presented later by Porter (1991) in his pursuit of a dynamic theory of strategy. Porter described how a company’s competitive position is created over time. He called this dynamic process the longitudinal problem and framed it in terms of the interactions between initial conditions and managerial choices. “The earlier one pushed back in the chain of causality, the more it seems that successive managerial choices and initial conditions external to the firm govern outcomes” (Porter 1991, p.106). Porter’s “successive managerial choices” is captured in the model’s representation of a continuous flow of decisions regarding staffing levels, resource allocation, and R&D objectives.

<u>Commoditization</u>

The experience of many technology-based markets suggested the existence of powerful long-term dynamics that lead to "commoditization" of products and services. This term is used to denote 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 These industries exhibit recurring cycles in investment, capacity utilization, prices, margins, and return on capital.

Examples range from lumber (West and Weil 1999) to IT (Carr 2003). Carr argues that infrastructure technologies inevitably commoditize, citing railroads, electric power, and communications. They become utilities that all businesses must use but not longer are a source of competitive advantage. “Many of the major suppliers of corporate IT... are battling to position themselves as dominant suppliers of web services – to turn themselves, in effect, into utilities” (Carr 2003, p.45). The airlines have gone through several boom and bust cycles since the US market was deregulated in the late 1970s.

My research illuminated the principal drivers of commoditization, key differences among industries and markets, leverage points for influencing the dynamics, and strategies for contending with commoditization. A generic market dynamics model was developed. It has been used to analyze the behavior of a cross-section of markets at different stages of maturity and liberalization, including airlines, telecommunications, petroleum, iron and steel, ocean shipping, IT, media, and pharmaceuticals (the model is described in Weil 1996; analysis results are presented in Weil and Stoughton 1998).

As depicted in Figure 3 this model represents the interactions among prices, demand, capacity loading, and profitability. Unlike the two models discussed above the unit of analysis is a market, not an individual company. Capacity planning, adoption of new technology, pricing, service quality, the effects of new entrants, and intensity of competition are modelled at the aggregate market level.

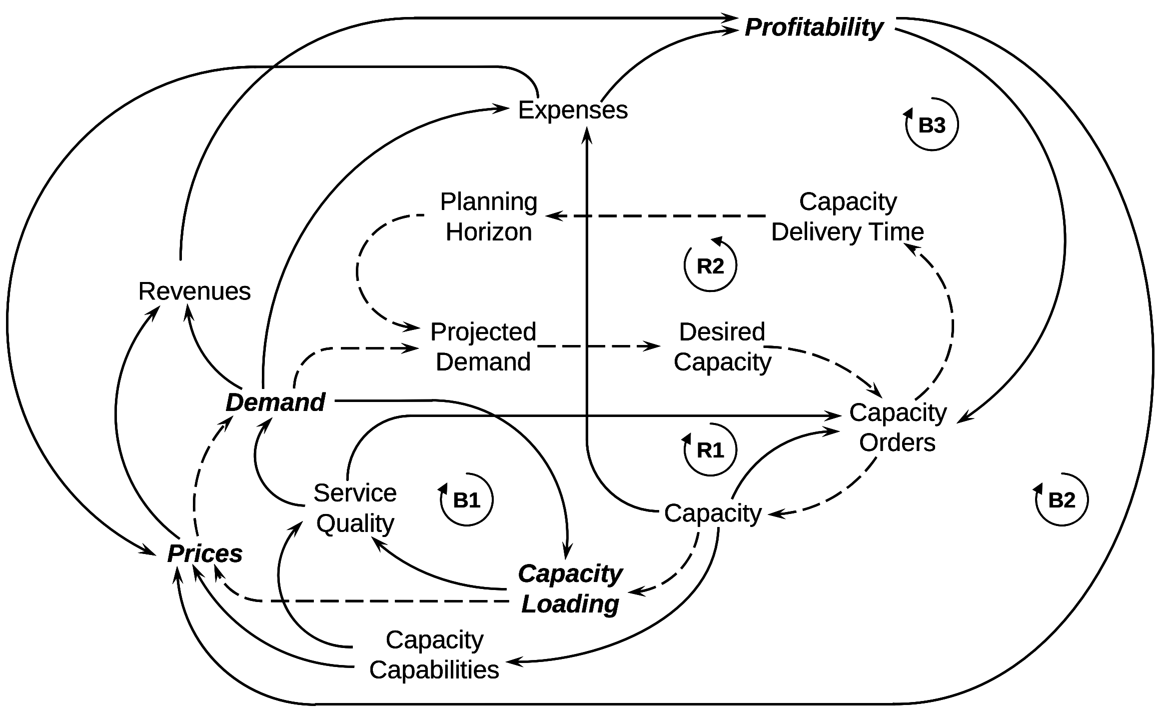

Figure 3: The Market Dynamics Model

The market dynamics model incorporates and builds upon the key features of earlier landmark models. Tension between the conflicting objectives of target capacity utilization and desired profitability strongly affect pricing and capacity decisions (balancing loops B1, B2, and B3). Pipeline constraints lead to long delays between capacity orders and when new capacity enters service, amplifying planning errors caused by extrapolation of past demand trends and biases toward over-optimism (reinforcing loop R2 shown in dashed lines).

This model differs in several important respects from a simple one-loop model of industry development where entry occurs, capacity rises, and prices fall until profits are driven out. First, increased capacity causes prices to decline and demand to grow, leading to further capacity orders (loop R1 also in dashed lines). Commoditization often creates a mass market which, for a period of time, grows much faster than would be explained by exogenous drivers, e.g., GDP or population. As described above, the second reinforcing loop (loop R2) raises capacity orders when the delivery time lengthens. It accelerates the build-up of excess capacity, especially when there are significant "barriers to exit."

The oscillating emphasis between capacity utilization and profitability (shifting dominance of loop R1 *vs*. loops R2 and R3) generate realistic dynamics observable in many markets, e.g., periods of steeply falling prices separated periods of price stability. The added complexity and richness of this model enable it to produce a wide range of commoditization behaviors. They allowed me analyze why commoditization happens very rapidly in some markets and more slowly in others.

Demand growth in commoditized markets tends to follow an irregular "stair step" pattern, driven by the combination of recurring cycles of over capacity and price cutting and macro-economic cycles. The distinctive pattern can be seen in Figure 4.

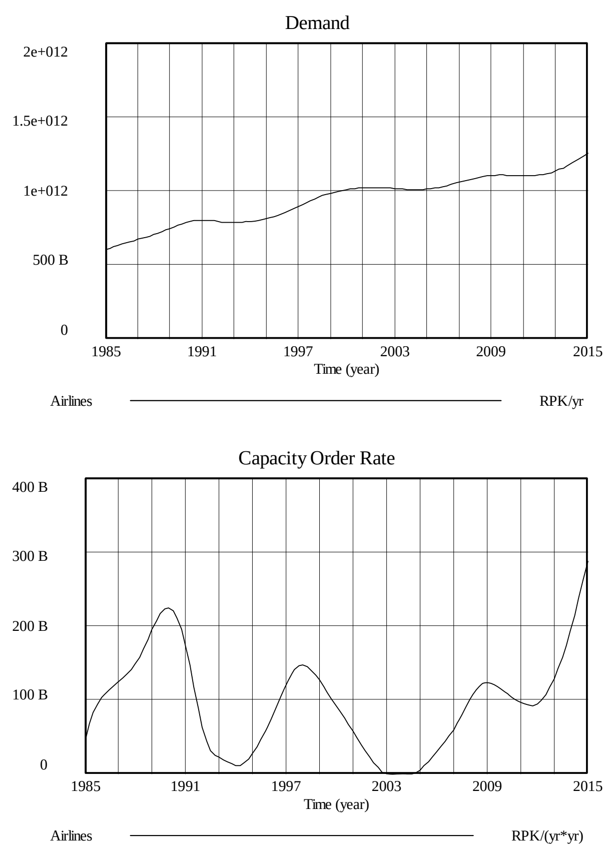

Figure 4: Output from the Airline Model

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.

The effects of technology on the industry's cost structure also are significant. If, as in the case of the airlines, the investment required per unit of capacity is rising the industry becomes dominated by fixed costs. This makes margins extremely sensitive to capacity utilization, and hence increasingly volatile. Conversely, as with telecoms during most of the simulated period, if technology is driving fixed costs down steadily, margins become less sensitive to utilization and in general more stable.

Capacity orders tend to become increasingly cyclical over time, with the down-cycles becoming lower and more extended. This pattern, shown in Figure 4, results from deteriorating industry profitability and increasingly strong profit and utilization effects on order decisions. It has profound implications for both the industries in question and their suppliers. Highly commoditized industries will have periodic opportunities to introduce new technologies, but these will be quite limited both in duration and relative to the installed base of capacity.

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.

"These results support the overarching conclusion that commoditization is driven by excess capacity. And they show that complex interactions over time among industry structure (e.g., the fragmentation and internationalization of markets), management policies (e.g., the response of pricing and investment decisions to capacity utilization and profitability), and technology strategy (e.g., the impacts of technology on costs and capabilities) underlie persistent excess capacity and, hence, commoditization" (Weil and Stoughton 1998, p.40).

The model was used to test a range of scenarios for factors which influence the industry-level dynamics, e.g., economic growth, technology trends, and regulation. The formal process of scenario development and use is closely identified with the Shell group. Wack (1985) and de Gues (1988) described why the process was initiated at Shell, how it worked there, and the practical benefits that were achieved.

Porter (1985) defined a ten-step process for developing and using scenarios. It is very significant that the first three steps involve a systematic micro-economic analysis of the industry in question. What is its structure? How does it function? What are the major uncertainties that might affect the industry? What are the sources of these uncertainties? To address such questions, managers must rely on some type of model. Another step requires managers to project the competitive situation under each scenario. How are they to do this? Again, some type of model is required. And the final step –

monitoring key factors to anticipate changes in the industry – depends on an ability to identify valid "leading indicators, " to interpret their movements correctly, and to know when to act. Here, too, managers inevitably employ some type of model.

There can be a very powerful synergy between scenario development and System Dynamics modelling. Scenarios consider multiple futures and force unconventional thinking. They can cause a team of managers to be more creative about important aspects of their business – operations, products, technology, markets, competition, government regulations, economic conditions. And, in so doing, they can change the mentality of senior managers. Scenario building requires managers to have a coherent view of their business. System Dynamics models can help managers to acquire this view. They provide a capability to identify which scenario variables are most important, to ensure the consistency of scenario assumptions, and to monitor key environmental factors.

The market model and research into commoditization have stimulated many Masters theses, five Doctoral dissertations (Stoughton 2000; Auh 2003; Ngai 2005; Dattée 2006; and one which will be completed this year), and a series of publications (for example, Weil 1996, Weil and Stoughton 1998, West and Weil 1999, Weil and Utterback 2005, and Dattée and Weil 2007). They have been enormously influential on my subsequent applications of System Dynamics to corporate strategy issues.

Technology Substitution

Ongoing research, initiated two years ago, captures and analyzes the fundamental dynamics of innovative industries with a System Dynamics model. By design the model is simple and generic. It is intended to apply to a broad range of products and services: assembled and process-based, complex and simple, physical and digital, business and consumer, early stage and mature, 19th century and 21st century. That is what is meant by the “fundamental dynamics” of innovative industries. In various combinations they can explain the evolution of most markets.

This work builds on an extensive body of research and publications. Its roots lie in the work of Abernathy and his collaboration with my colleague Jim Utterback. Over the ensuing years a rich collection of empirical studies, conceptual frameworks, and quantitative models of innovation were developed. (for example, Abernathy 1978; Abernathy and Utterback 1978; Abernathy and Clark 1985; Tushman and Anderson 1986; Henderson and Clark 1990; Klepper and Graddy 1990; Utterback and Suarez 1993; Utterback 1994; Milling 1996; Christensen 1997; Pistorius and Utterback 1997; Christensen, Suarez, and Utterback 1998; Utterback and Afuah 1998; Christensen and Overdorf 2000; Milling 2001).

The literature highlights dynamics which are fundamental to the sources of innovations and their impacts on firms, markets, and industries. When disruptive innovation enables a new generation of products or services the dominant companies in the market often are complacent and slow to react (this is the behavior of incumbents described in Sull 1999 and Christensen and Overdorf 2000). They seem unconcerned, uninterested or even dismissive. The new technology may be considered “inferior” or “a niche market.” It does not fit with the paradigm of the dominant companies and does not appear to be a sufficiently large opportunity.

While the established companies may participate in the new technology they usually focus most of their resources and attention on the older generation. Indeed, as they feel more and more pressure from the new generation the incumbents often find ways to substantially refresh the old technology, boosting its performance to much higher level. But typically they struggle to be successful with the new technology. Innovation obsoletes important aspects of the incumbents’ capabilities and knowledge, which tend to become deeply embedded in their structure and processes (see Cooper and Schendel 1976; Utterback and Kim 1986; Henderson and Clark 1990; and Utterback and Suarez 1993). The most frequent outcome is a change in market leadership.

The basic structure of the model is presented in Figure 5. This model connects the number of companies in the market, technology evolution, adoption of new technology, and the profitability of the companies. The other fundamental dynamics of innovation are represented, i.e., entry and exit of firms, improvements in cost and performance, market growth, intensity of competition, and commoditization. The model represents products based on two generations of technology. It first was applied to film and digital cameras. The second case study is CD and MP3 music players.

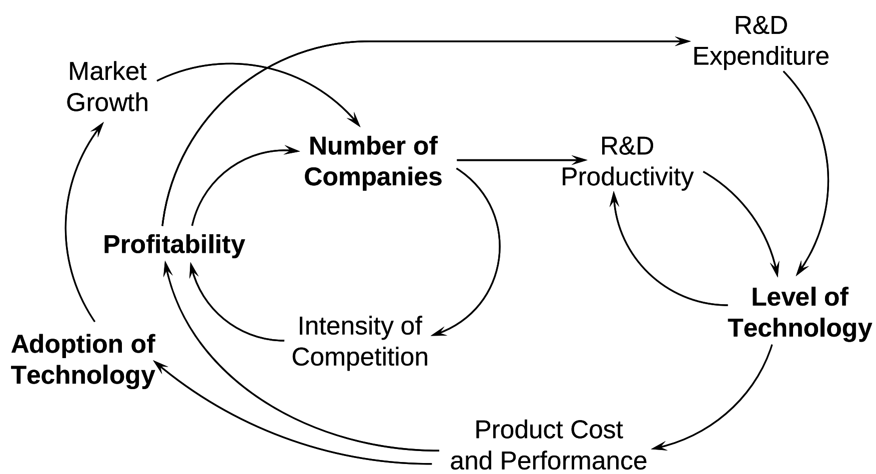

Figure 5: Innovation and Technology Adoption

The entry of firms into a market and the subsequent exit of many or most competitors are central to the dynamics of innovation (these dynamics are described in Utterback 1994). 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.

The large number of firms generates a high rate of experimentation and innovation. Continual innovation and the increasing number of users of a new technology drive improvements in cost and performance. The adoption rate of products or services based on a new technology depends on both the number of potential users and their willingness to adopt. Customers' willingness to adopt is affected by both objective and emotional factors, i.e., price/performance, network effects, and perceived risks. "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" (Weil and Utterback 2005, p.6).

As the market becomes more crowded and standards emerge, the intensity of competition increases and the products or services commoditize. This has two reinforcing effects on the number of firms. First, the entry rate slows because potential entrants reassess the attractiveness of the opportunity. Second, a growing number of firms exit the market. The rate of innovation slows and shifts from product to process.

Once again the model drew heavily on and added to the portfolio of building blocks. Conflicting performance pressures, i.e., from market share and profit objectives, influence the R&D expenditure of companies associated with both generations of technology. There are significant delays in the product development pipeline before R&D expenditures affect the level of technology in the companies and then the cost and performance of products in the market. Commoditization drives 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.

Significant conclusions emerged from this work. The "lemming effect" has enormous leverage. The inflow of companies stimulates technological progress, drives improvements in cost and performance, increases willingness to switch, and accelerates adoption of the new technology. The willingness to switch evolves in stages. 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.

Social Factors

Trust and brands are key elements in the dynamics of most markets. Powerful brands make decisions easier when customers are faced with many possibilities. They provide customers with a range of intangible benefits, e.g., peace of mind, recognition, individuality, status, a willingness to trust, and the confidence to empower. Brands promote and reward loyalty, thus creating stickiness in relationships. Customer information becomes the most valuable asset, especially in commoditized markets. Trust is the essential prerequisite for the customer to reveal personal information, authorize use of this information, and welcome the results. In the absence of sufficient trust likely customer behaviors are deliberate deception, holding back, and fending off.

Customer information management drives a dynamic model of relationship value. The model involves extremely powerful self-reinforcing mechanisms which can be either virtuous or vicious. Growing satisfaction and trust leads the customer to be more open regarding values and needs, and more willing to empower the service provider. As an empowered agent it can search, evaluate, advise, and implement on behalf of the customer. This "learn more, sever better" model (Weil and Weil 2001) is shown in Figure 6. It is central to value creation in commoditized markets.

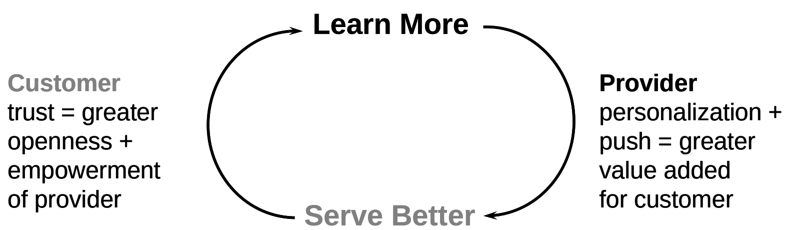

Figure 6: A Model of Relationship Value

"The easiest way to ruin a relationship is to frustrate, disappoint, irritate, or abuse the customer, e.g., by over-stepping the bounds of what he or she at any point considers 'acceptable behavior'" (Weil and Weil 2001, p.10) The provider needs to measure the state of relationships, and not move too fast or too slowly. The imperative is demonstrate commitment, respect, and trustworthiness.

My most recent work focuses on the market impacts of social factors, e.g., trust, fashion, lead users, perception and extrapolation of trends, information flows, bandwagon effects, and network effects. I am collaborating with two colleagues at Imperial College London, Nelson Phillips and Brice Dattée (see Munir and Phillips 2002; Dattée 2006; Dattée and Weil 2007). 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.

My case study of the spectacularly successful iPod highlights the importance of social factors in innovation and technology adoption. How did Apple de-commoditize music? What exactly is innovative about the iPod? First, the timing was right. Successful prosecution of Napster and individuals who flagrantly violated IP rights publicized the criminal nature of unauthorized file sharing. The major music publishers were experiencing declining sales of traditional media, belatedly recognized the potential of online distribution, and were ready to do a deal with a responsible distributor who offered IP protection.

Equally important, Apple recognized that as a market matures and commoditizes the sources of competitive advantage become increasingly intangible, e.g., brand, customer insights, design, marketing, lead users, and the customer experience. Apple used its counter-culture brand, elegant product design, and dramatic advertising to create a social phenomenon. The customer experience was great. The iPod made digital music intuitive and easy (the interface, installing and using the software, downloading music). Pine and Gilmore (1998) describe the progression of economic value from commodities, to goods, services, and then experiences. "This transition from selling services to selling experiences will be no easier for established companies than the last great economic shift, from the industrial to the service economy" (Pine and Gilmore 1998, p.98).

Strong bandwagon and network effects reinforced the virtuous dynamics. 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. Podcasting increased the value of the iPod disproportional to the number of users. Two further lessons from the iPod are the importance of complementary assets (iTunes and accessories) and of continual incremental innovation to further reinforce the dynamics (new music players, the photo iPod, and video iPod).

The commercial model of the iPod exploits these bandwagon, network, complementary asset, and innovation effects. The iPod appliance is the principal revenue and profit generator. The iTunes site offers copyrighted music tracks and video content for fees and lists over 20,000 free podcasters. The role of iTunes is to make the iPod more valuable to users. Apple has stimulated a rich ecology of independent accessory suppliers, e.g., of cases, docks, speakers, and remote controls, and filled potentially vulnerable gaps in its product range with low price basic models and a series of higher-end models with increasingly sophisticated capabilities.

As noted above the model of innovation and technology adoption was applied to CD and MP3 music players. A number of extensions to the original model were required to capture the more complex dynamics of this market. They are shown in Figure 7.

Advances in product technology are strongly influenced by the cost and performance of components, e.g., disk drives, flash memory, and USB interfaces for MP3 players. The key hardware innovations were at the component level, not in the appliances. Increased ease of use of products based on the new technology accelerated adoption. In the case of MP3 players the widespread adoption of broadband communications dramatically improved the speed at which music and video files could be downloaded. A strong positive feedback loop connected adoption with the availability of complementary assets, in this case content and accessories. Finally another positive feedback loop captured the bandwagon effect. As more people adopted products based on the new technology they became fashionable, cool, and a must have.

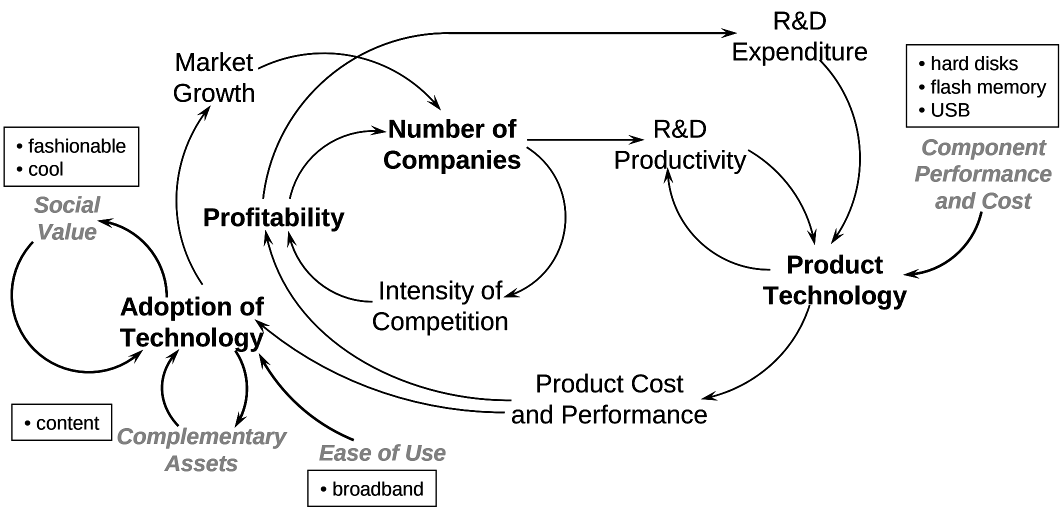

Figure 7: The CD/MP3 Model

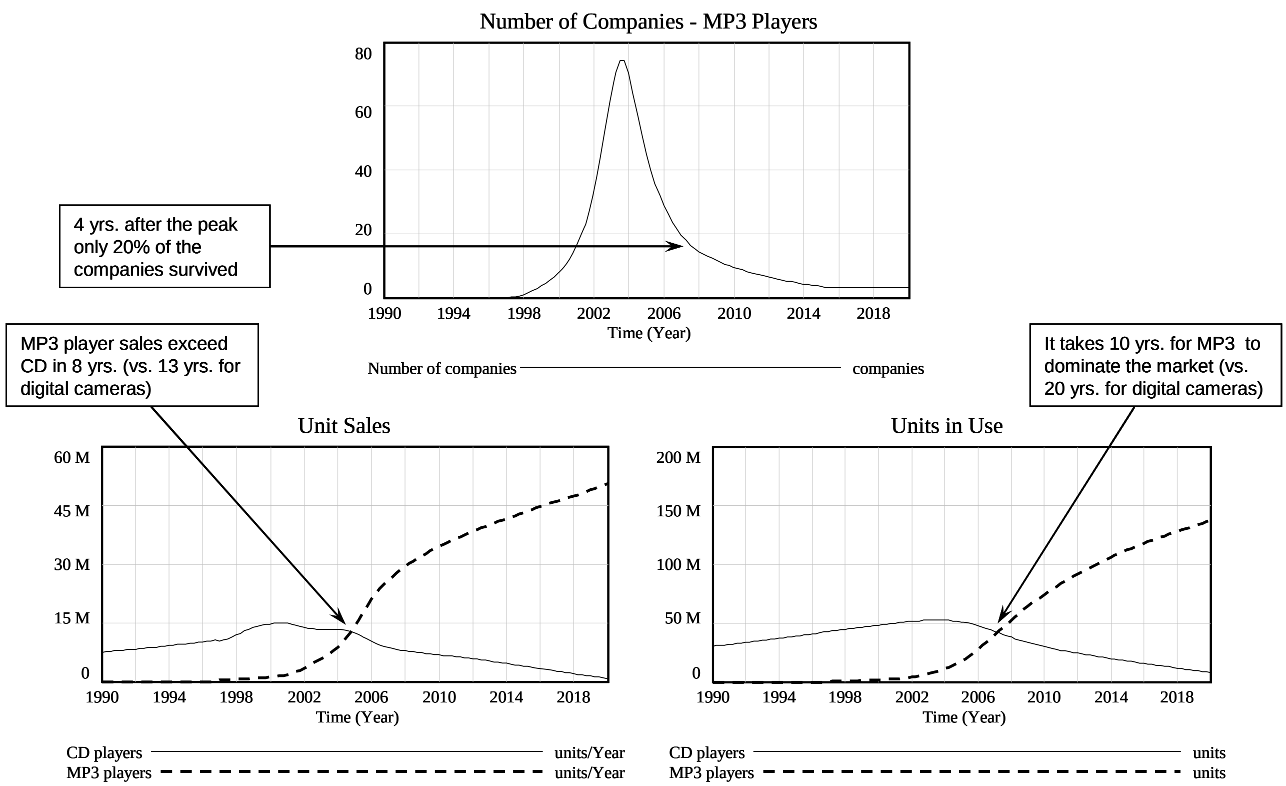

Figure 8: Output from the CD/MP3 Model

Results from the CD/MP3 model are presented in Figure 8. Not surprisingly the additional structure changed the dynamics. Driven by the positive feedback loops the adoption of MP3 progressed rapidly. MP3 player sales exceed CD in 8 years *vs*. 13 years for digital cameras. It takes 10 years for MP3 to dominate the installed base *vs*. 20 years for digital cameras. The failure rate of market entrants is spectacular. In four years the number of companies offering MP3 players declines from a peak of almost 80 to 15, i.e., only 20% have survived.

"A more complete model of technology diffusion that accounts for the dynamics of social factors can replicate more accurately non-trivial substitution patterns. It also indicates that more effective targeting of opinion leaders as early adopters could provide effective leverage from communication because of their relevance and credibility as reference users. Understanding, the dynamics induced by the structure of interpersonal networks can... reduce the risk of misreading the market. Such risks include giving up too soon, overconfidence, and the risk of a technological spark that fails to achieve mainstream take-off" (Dattée and Weil 2006, p.1).

Epilogue

It has been a long and productive journey. I started with classical Industrial Dynamics, models of the firm which focused on orders, production, and shipments. At each milestone I recognized and represented more behavioral richness and complexity. Along the way the strategic issues on which I worked evolved from the internal business dynamics of the firm to competition and the longer-term behavior of markets, particularly markets where technology is an important factor.

Commoditization results from complex interactions among market structure, competitive behavior, and new technologies. Aspects of organizational behavior are central to these dynamics. New entrants usually put market share growth ahead of short-term profitability for a period of time (often the first 2-3 years in "J-curve" business plans). At some point the established incumbents feel compelled to sacrifice profitability in order to defend their positions. Traditional barriers to entry and conservatism in decision making are eroded by freely available financing. When an industry is "hot" entrepreneurs have no difficulty raising the capital to launch new companies. 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." Competing on intangibles requires quite different capabilities from competing on product or service price and performance.

My work on technology substitution took me deeper into the social and psychological dynamics of markets. How potential adopters respond to something which is new and unproven, but fresh and cool is quite complex. The fluidity and uncertainties of the early stage poses significant risks for customers. 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." The "lemming effect,". i.e., the wave of entrants into a market during the early fluid stage of a new generation of technology, is a key driver of experimentation, innovation, and technological progress.

A social perspective on innovation explains why it is necessary for most companies to change the way they interact with customers. Successful innovations build on customer needs and create positive behavioral change among large groups. Customers, not suppliers, define "quality." The innovations which create real value for companies, e.g., the iPod, are not primarily about technology. The winners are companies who manage the social side of technology: the complete customer experience.

What do we know now that we did not know forty years ago? The most important lessons for me were about the critical roles of organizational, social, and psychological factors in business decisions, competitive behaviors, and the evolution of markets. I now think of business dynamics at three inter-related levels: the organizational level, market level, and contextual level. My work highlights the critical importance of human and intellectual capital, e.g., skilled scientists and engineers, suppliers and other complementors, familiarity with technologies and markets, insights regarding customer needs and values, and customers with an appetite for innovations.

To quote my favorite Chinese cookie fortune, "The road to success is always under construction."

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