Innovation: Mapping the winds of creative destruction *

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This paper develops a framework for analyzing the competitive implications of innovation. The framework is based on the concept of transilience – the capacity of an innovation to influence the established systems of production and marketing. Application of the concept results in a categorization of innovation into four types. Examples from the technical history of the US auto industry are used to illustrate the concepts and their applicability. The analysis shows that the categories of innovation are closely linked to different patterns of evolution and to different managerial environments. Special emphasis is placed on the role of incremental technical change in shaping competition and on the possibilities for a technology based reversal in the process of industrial maturity.

1. Introduction

Technological innovation has been a powerful force for industrial development, productivity growth and indeed, our rising standard of living throughout history, but intense study of its industrial role and influence is a relatively recent phenomenon. In traditional economics, it has long been customary to treat technological innovation as something that happened to the economic system but was not determined within it [1]. Some recent work has examined the determinants of innovation, with emphasis on the role of market demand and the influence of market structure. The focus has not been on the process of innovation itself, but rather on those aspects of the firm's (or industry's) environment that spur or retard technical advance [2].

In contrast to the bulk of economic analysis, the work of technologists and behavioral scientists has focused on what goes on inside the black box of technology. In this line of work, innovation is viewed as a sequence of activities involving the acquisition, transfer and utilization of information [3]. Although the importance of activities outside the firm (or project) is often recognized, the orientation of these studies is internal. Of principal concern are personality traits of individuals, the origin of innovative ideas and the way that administrative practices and organization structure influence their development. In this work, however, the internal traits of the firm have not been well linked to the competitive requirements of firms or industries.

More recently studies by Porter, Rosenbloom, Rosenberg, Nelson and Winter, and others, have begun to illuminate some of the important aspects of the relationship between innovation and competition [4]. While earlier work tended to deal with the effect of structural characteristics (i.e. levels of hierarchy, firm size, concentration) and admin-

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istrative practices on innovation, these new studies have begun to ask questions about innovation's role in shaping the competitive environment.

Regrettably however, the conclusions Rosenbloom drew in his comprehensive review of the literature on innovation are largely as applicable today as they were ten years ago [6]. Notwithstanding some interesting findings, he concluded that results from this field offered little guidance to either the public policy maker or the business manager who must contend with practical aspects of technology investment and use.

As a remedy for this plight, Rosenbloom called for the development of a conceptual framework that would integrate knowledge concerning technology to other policy arenas of the firm (i.e. marketing, finance, operations, etc.). Without a schema that managers might apply to develop and communicate perspectives on technology throughout their organizations, it is not surprising that technology and its management have received little systematic attention in the formulation and implementation of policy.

The challenge of formulating such a framework for technology policy marks the point of departure of the present work. Our purpose in this paper is to develop a descriptive framework that may be useful in categorizing innovations and analyzing the varied role they play in competition. The framework recognizes that innovation is not a unified phenomenon: some innovations disrupt, destroy and make obsolete established competence; others refine and improve. Further, the effects of innovation on production systems may be quite different from their effects on linkages to customers and markets. The framework reflects these differences, as well as the important notion (developed in the work of Burns and Stalker, and others) that different kinds of innovation require different kinds of organizational environments and different managerial skills. Our intent is thus to develop concepts that may prove useful in the effort to incorporate technological considerations into business strategy, and perhaps in developing appropriate public policies.

We explicate the model through intensive analysis of the technical and competitive history of the US auto industry. An in-depth look at a particular industry provides a level of detail that seems essential in making the kinds of distinctions we are after. We thus do not offer the auto story as a representation of the whole economy, but rather see it as a source of useful examples. Further, the use of an historical perspective in explaining the framework is deliberate. We are interested in the pattern of technological development and competitive rivalry over time. In our emphasis on the pattern of development over time and our conception of competition as a contest among rivals (actual and potential) with different capabilities, the model we develop is evolutionary in spirit.

The paper is divided into three parts. In section 2 we develop criteria for categorizing innovation in terms of its competitive significance. The criteria are based on the notion that competitive advantage depends on the acquisition or development of particular skills, relationships and resources. How innovation affects those requirements can be used to gauge its significance. Building on these concepts, section 2 further identifies four different "modes" of innovation, and uses examples from the auto industry to illustrate them. In section 3 we relate the different kinds of innovation to the pattern of industry evolution. Special emphasis is placed on the role of incremental technical change in shaping competition, and on the possibilities for a technology based reversal in the process of industrial maturity. The paper concludes (section 4) with observations on implications for practice and further research.

2. Identifying the role of innovation in competition: The transilience map

The first step in developing a categorization of innovation is to get straight the question of perspective. Technological innovation may influence a variety of economic actors in a variety of ways, and it is this variety that gives rise to differing views of the significance of changes in technology. What may be a startling breakthrough to the engineer, may be completely unremarkable as far as the user of the product is concerned. In this paper we shall evaluate innovation in terms of its implications for the success (or failure) of the innovating firm in its rivalry with competitors. We are thus concerned with how, and to what extent, innovation affects the relative advantages of actual and potential competitors.

The notion of competitive advantage that we use here is broader than the differences in costs among competitors. Without minimizing the importance of cost in competition, we propose to consider the competitive position of a firm in terms of a variety of dimensions. We assume therefore that products are not homogeneous, and that firms compete by offering products that may differ in many aspects: performance, reliability, availability, ease of use, aesthetic appearance, and image (among others), as well as initial cost. A firm gains a competitive advantage when it achieves a position in one of these featured dimensions, or a combination of them, that is both valued by customers and superior to that of its competitors.

It is important to note that the product features themselves, and the firm's position with them, are not in and of themselves the fundamental source of advantage. Such a position is the immediate, outward manifestation of a more fundamental, internal reality. The foundation of a firm's position rests on a set of material resources, human skills and relationships, and relevant knowledge. These are the competencies or competitive ingredients from which the firm builds the product features that appeal to the marketplace. Thus, the significance of innovation for competition depends on what we shall call its "transilience" – that is, its capacity to influence the firm's existing resources, skills and knowledge [6].

Table 1 presents a list of the major competitive ingredients divided into two groups. In the top half of the table we have placed the factors that determine the capabilities of the firm in technology and production. For ease of notation, we shall refer to this set as the "Technology" side of the firm, but mean it to include production and operations as well. The resources, skills and knowledge within this domain are linked to competition through their effect on the physical characteristics

Table 1
Innovation and firm competence

Domain of innovative activity	Range of impact of innovation		
I. *Technology/Production*			
Design/embodiment of technology	improves/perfects established design	↔	offers new design/radical departure from past embodiment
Production systems/organization	strengthens existing structure	↔	makes existing structure obsolete demands new system, procedures, organization.
Skills (labor, managerial, technical)	extends viability of existing skills	↔	destroys value of existing expertise
Materials/supplier relations	reinforces application of current materials/ suppliers	↔	extensive material substitution; opening new relations with new vendors
Capital equipment	Extends existing capital	↔	extensive replacement of existing capital with new types of equipment
Knowledge and experience base	builds on an reinforces applicability of existing knowledge	↔	establishes links to whole new scientific discipline/destroys value of existing knowledge base
II. *Market/Customer*			
Relationship with customer base	strengthens ties with established customers	↔	attracts extensive new customer group/creates new market
Customer applications	improves service in established application	↔	creates new set of applications/ new set of customer needs
Channels of distribution and service	builds on and enhances the effectiveness of established distribution network/service organization	↔	requires new channels of distribution/new service, after market support
Customer knowledge	uses and extends customer knowledge and experience in established product	↔	intensive new knowledge demand of customer; destroys value of customer experience
Modes of customer communication	reinforce existing modes/methods of communication	↔	totally new modes of communication required (e.g. field sales engineers)

of the product – its performance, appearance, quality, and so on – and through its cost. The list includes traditional factors of production like materials, people, building and equipment, as well as knowledge relevant to design and production. This not only includes links to scientific, engineering and design disciplines, but it also includes the knowledge embedded in the systems and procedures used to organize production.

In this formulation we make a distinction between the skills and the knowledge embodied in individuals and the collective understanding shared among groups of employees, and partly incorporated into teamwork routines, procedures, practices, and so forth. We make a further distinction between the factors of production – labor, capital and materials – and their organization and deployment. We assume that a given set of inputs can be combined and organized in a variety of ways to achieve different results, either technically in terms of the sequencing of operations and factor combinations, or organizationally in terms of systems for acquiring and processing information. The infrastructure of production – e.g. organization, system, procedures – thus merits separate consideration.

The second half of table 1 is devoted to markets and linkages to customers. Of central importance in this domain is the relationship with the customer base. We include in this category both the strength of the relationship, as well as the composition of the customer group. The other items in this domain affect the way in which customers relate to the product. We make a distinction between the applications the product serves, and the knowledge and experience required in the product's use. Further, we have included both the way in which customers obtain the product and related services, and the way in which they obtain information about its characteristics.

Each item listed in the table is accompanied by a scale that depicts the range of effects an innovation might have. In each case the range is defined by polar extremes, the one conservative, the other radical. On the conservative end of the scale are those innovations that serve to enhance the value or applicability of the firm's existing competence. Clearly, all technological innovation imposes change of some kind, but change need not be destructive. Innovation in product technology may solve problems or eliminate flaws in a design that makes existing channels of distribution more attractive and effective. Further, innovation in process technology may require new procedures in handling information, but utilize existing labour skills in a more effective way. Such changes conserve the established competence of the firm, and if the enhancement or refinement is considerable, may actually entrench those skills, making it more difficult for alternative resources or skills to achieve an advantage. Such innovation may have an effect on competition by raising barriers to entry, reducing the threat of substitute products, and making competing technologies (and perhaps firms) less attractive.

On the radical end of the scale, the effect of innovation is quite the opposite. Instead of enhancing and strengthening, innovation of this sort disrupts and destroys. It changes the technology of process or product in a way that imposes requirements that the existing resources, skills and knowledge satisfy poorly or not at all. The effect is thus to reduce the value of existing competence, and in the extreme case, to render it obsolete. This kind of change is at the heart of Schumpeter's theory of innovation and economic development in which "creative destruction" is the vehicle of growth [7]. Its effect on competition works through a redefinition of what is required to achieve a competitive advantage. In strong form, where disruption is both deep and extensive, such innovation creates new industries.

In the framework laid out in table 1 the significance of an innovation for competitive advantage depends on more than technical novelty or scientific merit. In an age of gene splicing and other scientific marvels that do indeed create new industries and destroy old ones, it is easy to develop a stereotype of innovation that may obscure judgements about technical change and its significance for competition. One need only take the effects listed on the right hand side of table 1 to obtain the following exaggeration:

> An innovation is the initial market introduction of a new product or process whose design departs radically from past practice. It is derived from advances in science, and its introduction makes existing knowledge in that application obsolete. It creates new markets, supports freshly articulated user needs in the new functions it offers, and in

> practice demands new channels of distribution and aftermarket support. In its wake it leaves obsolete firms, practices, and factors of production, while creating a new industry.

This is a stereotype of an ideal that is both rarely encountered in practice and misleading. Novelty and connection with scientific advance may have little to do with an innovation's competitive significance. The entry of the Timex Corporation into the watch industry provides a useful example [8]. Its success in the market was based on refinements of an old technology (pin lever movement), that was applied in upgraded styling and offered through new channels of distribution (drug stores, discount houses). Using standardization of parts, mechanization, low skilled labor and precision tooling, Timex produced a consistent, durable product, at very low cost. Its use of hard alloy bearings avoided the need for jewels, and its simple design made complex adjustments unnecessary. Further, the company employed a cadre of engineers and technicians to design and build its own tooling and production equipment. In combination with modern styling and an aggressive marketing strategy, the refinements in product and process design gave Timex a significant competitive advantage.

The refinements in technology undertaken by Timex in conjunction with an appropriate business plan provided competitive leverage out of proportion to the technical changes involved. In so doing, they provided the basis for an assault on established barriers to entry that had been built through franchise sales, service and repair, and status connected imagery. Thus, what were a series of relatively mundane changes in technology, came to have major ramifications in the market.

The Timex example reinforces the notion that the competitive significance of an innovation depends on what it does to the value and applicability of established competence – that is, on its transilience. But the example also illustrates the importance of distinguishing between effects on markets and effects on technology or systems of production. A given innovation may affect the two domains in quite different ways. It is the particular combination or pattern of technology and market transilience that is important in determining competitive impact. One way to depict the pattern of effects is to use composite transilience scales for each domain as the axes of a two-dimensional diagram. In fig. 1 we have positioned the market transilience scale in the vertical dimension, and the technology transilience scale in the horizontal. This creates a "transilience map", with four quadrants representing a different kind of innovation. Working counter clockwise from the upper righthand corner, the categories of innovation are: Architectural, Niche, Regular, and Revolutionary. We shall illustrate each category using examples from the US automobile industry; specific innovations in each group are presented in table 2. Further, in section 3 we show that the categories are closely linked to patterns of industry development, and that the four quadrants represent phases of innovative development. Moreover, this categorization of innovative effects is linked to other differences in the evolution of firms and industries, so that the four quadrants also represent different managerial environments.

2.1. Architectural innovation

New technology that departs from established systems of production, and in turn opens up new linkages to markets and users, is characteristic of the creation of new industries as well as the reformation of old ones. Innovation of this sort defines the basic configuration of product and process, and establishes the technical and marketing agendas that will guide subsequent development. In effect, it lays down the architecture of the industry, the broad framework within which competition will occur and develop. We have thus labelled innovation of this sort "Architectural"; it is graphed in the upper right hand quadrant of the transilience map.

Whether it creates a new industry like xerography or radio, or whether it reformulates an established industry as with photo typesetting in the printing industry, architectural innovation seems to involve a process and an organizational climate that is distinctive. The Charpie report, the work of Burns and Stalker, and research by Jewkes, Sawyers and Stillerman, suggest that entrepreneurial action occurs in a unique managerial climate and with firms whose organizational structure is not bureaucratic and rigid [9]. The potential for stimulating architectural innovation seems to hinge on the juxtaposition of individuals with prior experience in relevant technologies and new user

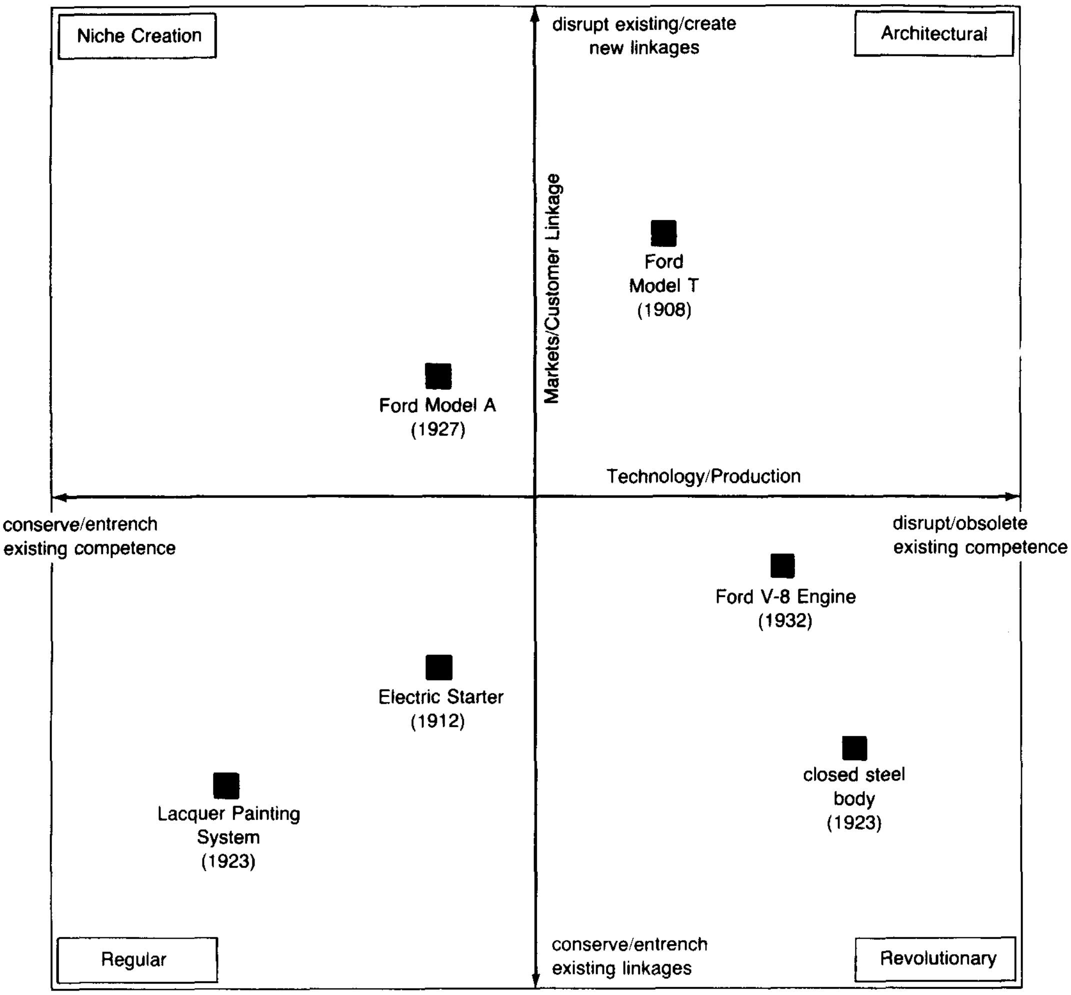


Fig. 1. Transilience map and selected automotive innovations.

environments latent with needs. These insights are well illustrated in the case of the early development of the US automobile industry [10].

The early years of this century marked a turbulent era in the technological development of the motorless carriage. Early cars were made by bicycle manufacturers and wagon makers, and the designs reflected each prototype's origin. Technologies from these industries as well as locomotive manufacturing and the electrical industry were competing to serve an emerging market for personal transportation. What developed out of the contest among diverse design concepts was a creative synthesis that established the architecture of product and process. The dominant producer in that development was Ford, and the dominant product, the Model T. The first panel in table 2 presents a list of some of the major technological innovations in the architectural era with special emphasis on the design concepts embodied in the Model T.

Three themes are evident in this architectural pattern of innovation. The first is the importance of breaking the grip of the prior industries on the technological structure of the new industry. Second is the durability of the concepts. The designs that constitute the creative synthesis in this period stand for a very long time in the industry's future. The third theme is the role of science. Although science-based innovations are apparent as underpinnings of the dominant design, the overall design itself is not stimulated by science. These observations find support in the specific innovations in table 2. From 1903 to 1907, the spark advance,

Table 2
Selected automotive innovations

Innovation	Year	Company
I. Architectural innovations		
Left hand steering	1990	G and J Jeffrey
Front mounted engine	1900	most producers
Planetary transmission	1902	Northern
Unitary engine and transmission	1902	Northern
Magneto integrated into flywheel	1908	Ford
Removable cylinder heads	1908	Ford
Vanadium crankshaft	1908	Ford
II. Market Niche innovation		
Safety glass	1926	Rickenbacker, Stutz
Streamlined bodies 1934	Chrysler	
Station wagon	1923	Star
Hardtop convertible	1946	Chrysler
Bucket seats	1959	GM
Wide-track chassis	1959	GM
Low-priced sports car (Mustang)	1965)	Ford
III. Regular innovation		
Electric starter	1912	GM
Moving assembly line	1913	Ford
Lacquer finish (DUCO-pyroxolin)	1924	GM
Rubber engine mounts	1922	Nash
Constant temp. inspection room	1924	Ford
Automatic welding	1925	Budd
Thin wall gray cast iron engine	1959	Ford
IV. Revolutionary innovation		
Closed steel body	1922	Hudson
V-8 engine cast en-bloc	1934	Ford
Automatic transmission	1940	GM
Cast steel cam and crankshaft	1934	Ford
Independent suspension	1934	GM
Unit body construction	1936	Ford

Source: W.J. Abernathy et al., *Industrial Renaissance* (Basic Books, New York, 1983), Appendix D, pp. 150–179.

the longitudinal mounting of engines, torque tubes for drive shafts and bevel gear systems were introduced in successive Ford models. They were supported by a series of innovations in manufacturing processes: multiple machining, new assembly methods and so forth. Many of these concepts remained the industry standard for decades, and part of their success lies in their departure from the design rules of wagon makers and locomotive manufacturers. The spark advance and the torque tube, for example, marked a mating of technologies – electrical control concepts to the thermodynamics of engine design, and the dynamics of torque in motored propulsion to chassis design – that advanced and displaced the conventions of carriage makers.

Breaking out of the confines of established industries not only influenced technical development, but also opened up new possibilities in linkages to markets and customers. The market implications of the innovations of this period are well illustrated in the case of the flywheel magneto and vanadium steel alloy. The flywheel magneto provided an electrical power source for firing the spark plugs that was built into the engine. This ingenious integration of new electrical technology with engine design meant that the car could be used in remote locations and would not be vulnerable to the life of the dry cell or other batteries for ignition. In similar fashion, the application of vanadium steel alloy in engines and chassis components was an important part of the development of a lightweight vehicle. When Ford and his engineers found an alloy that afforded three times the design strength of traditional materials, it freed them to apply new concepts of lightweight design to many parts. As a result they were released from many old constraints that had been adopted from carriage technologies. The engine and the chassis came to be based on concepts of flexible lightweight structural design as opposed to the more traditional designs that sought durability through stout rigidity.

Improved reliability and lightweight design were important elements in the creation of a rugged, durable vehicle, able to withstand the rigors of rural operation, and yet sufficiently low cost to permit the development of a mass market. Technological innovation thus gave Ford the kind of product he needed to open up a new market and establish a new set of applications. Design concepts like the integrated flywheel and new alloys were essential to the development of a rural market for basic transportation – for a people's utilitarian vehicle that could go anywhere and was relatively easy to maintain. This was a product concept that made possible new distribution channels and new types of aftermarket support, and thus broke many of the marketing conventions of the day.

Our location of the Model T in the Architecture quadrant of fig. 1 reflects the fact that its transilience was greater in the market dimension. Though there were some disruptive elements in its technology, its genius lay more in a creative synthesis of technology innovated by its diverse predecessors. The Model T experience thus suggests that architectural innovations stand out as creative acts of adapting and applying latent technologies to previously unarticularted user needs. It is the insight and conception about fresh roles for existing inventions and technologies that mark this kind of innovation. Scientific work plays a part in freeing thought, and relaxing old rules of thumb. The challenge lies in linking understanding of technical possibilities to insights about unarticulated needs.

2.2. Innovation in the market niche phase

Using new concepts in technology to forge new market linkages is the essence of architectural innovation. Opening new market opportunities through the use of existing technology is central to the kind of innovation we have labelled "Niche Creation", but here the effect on production and technical systems is to conserve and strengthen established designs. There are numerous examples of niche creation innovation, ranging from the Timex example referred to earlier, to producers of fashion apparel, and consumer electronics products. The mating of light weight earphones and a portable radio or casette player in Sony's Walkman, used established technologies to create a new niche in personal audio products. Makers of women's apparel have traditionally used changes in ornamentation, color, configuration, fabrics and finishes to create profitable if transitory market niches. Innovation of this sort represents what Utterback has called "sales maximization", in which an otherwise stable and well specified technology is refined, improved or changed in a way that supports a new marketing thrust. In some instances, niche creation involves a truly trivial change in technology, in which the impact on productive systems and technical knowledge is incremental. But this type of innovation may also appear in concert with significant new product introductions, vigorous competition on the basis of features, technical refinements, and even technological shifts. The important point is that these changes build on established technical competence, and improve its applicability in the emerging market segments.

It is clear that successful niche creation innovation requires the matching of customer needs with refinements in technology. But the evidence suggests that such an alignment is in and of itself not sufficient to establish a long term competitive advantage. Innovation that helps to create a niche may be important, even essential, to the continued existence of the innovating firms. But if the innovation is readily copied, its competitive significance may be greatly diminished. Such was the experience of Ford with the introduction of the Model A in 1927.

By 1926 Ford had sold more 15 million Model Ts, and had driven the price as low as $290 on some models. Yet the Model T was a 20-year-old product whose basic design could not economically accommodate the range of new features and levels of performance demanded in the marketplace. The market was no longer dominated by rural buyers interested in rugged durability. Emphasis in the market was moving towards urban customers and the Model T's competitors offered improved power, increased comfort and convenience, and easier operation. Though Ford had created the world's largest industrial complex and had reduced costs significantly, demand for the Model T declined in the mid-1920s. With no new products in the pipeline, Ford decided in 1926 to shut down the giant Rouge River facility for nine months and develop the Model A.

With little time for development, and with a need to meet the demands of an emerging new market, it was almost inevitable that Ford would rely on established technology and thus move into a niche creation mode of innovation. Where GM had approached the changing market with new-concepts in design and in product development (i.e. constantly upgraded product technology), Ford responded with a major model change, but not with a technologically dynamic strategy (see fig. 1).

The Model A was introduced in late 1927 and was a great success. Ford's first completely redesigned model in 20 years aroused great public interest. Its appeal stemmed from the combination of features, the refinements and improvements in existing design concepts, and major advances in performance and styling. The new engine was light, but powerful. The car was capable of high speed, yet offered a smooth and quiet ride. Craftsmanship was evident in the fit of the body and the appearance of the interior and trim. And as far as styling was concerned, the Model A was lower and sleeker than the Model T, and color coordinated paint and fabrics were offered.

In its basic design, the Model A was a synthesis and refinement of concepts that had been introduced by other manufacturers. There was a margin of innovation in technology (e.g. mushroom valve stems, laminated safety glass, resistance welding), and a creative improvement and packaging of existing elements. Much of the improved engine performance, for example, came from improvements in existing machining processes. Smoothness and quietness of ride came from design changes that eliminated joints, the liberal use of sound deadening material, and the introduction of hydraulic shock absorbers.

In its overall configuration, the Model A gave definition to an emerging market segment (the moderately priced family car – good performance, modern styling, comfortable, convenient) through incremental innovation. It was sold through existing channels of distribution, but forged links to a new customer base, and defined new applications. These changes in market segment composition and definition has a further effect in changing methods of customer communication and influenced the delivery of aftermarket services. The Model A was thus moderately transilient in the market dimension, while building on and strengthening technical competence. Its introduction was critical to Ford's survival and enabled the company to regain market leadership from GM. But the triumph was short lived. By 1929, Chevrolet had developed new models that were a little bigger, a little faster, and a little more comfortable and stylish. That pattern continued in the 1930s as GM consolidated its market position.

The Model A's market share gains were not durable because competitors were able to copy and even advance the design quite easily. Unlike the Model T, the new design was not based on company developed innovations. The technological advances in the car involved either the application of new materials developed by others, small changes to existing components or features, or manufacturing advances that could be copied or that failed to lead to unique product features of value in the market. The Model A offered a technical configuration that was on target in the market, but that gave Ford no unique competitive strength on which to build a sustainable advantage. A similar conclusion applied to the other market niche innovations listed in the second panel of table 2.

The experience of the Model A seems to be characteristic of niche creation innovation. Such changes in technology may be associated with highly visible and transilient changes in the market, but any competitive gains from one particular innovation are likely to be transitory. No matter how well the new design meets the current demands of the market, the lasting significance of an innovation will be greatly reduced if the new technology is insufficiently unique to defy ready acquisition by competitors. But that does not imply that innovation is of no importance in markets characterized by niche creation. Rather, it suggests that the advantage derived from a given innovation will be temporary, and that long term success in this mode will require a sequence of new products and processes to counter the moves of rivals. It appears that in niche creation innovation, timing and quick reaction are everything.

2.3. Regular innovation

The creation of niches and the laying down of a new architecture involve innovation that is visible and after the fact apparently logical. In contrast, what we call "Regular" innovation is often almost invisible, yet can have a dramatic cumulative effect on product cost and performance. Regular innovation involves change that builds on established technical and production competence and that is applied to existing markets and customers. The effect of these changes is to entrench existing skills and resources.

Research on rocket engines, computers and synthetic fibers has shown that regular innovation can have a dramatic effect on product cost, reliability, and performance. Although the changes involved may be minor when examined individually, their cumulative effect often exceeds the effect of the original invention. This same pattern is evident in the dramatic declines in price and the improved reliability of the early Model T. From 1908 to 1926, the price of the car fell from $1200 to $290, while the productivity of labor and capital increased markedly. These reductions in cost were the result of numerous changes in the process, most of which Ford himself thought to be too insignificant to recount. While improvements in casting, welding and assembly, and material substitution helped to reduce cost, they also interacted with changes in the product to improve reliability and performance. Electric lights, enamel finishes on the body, rubber engine mounts and an integral brake drum and hub, are examples of the kinds of changes in product design that improved the Model T's appeal in the market.

Regular innovation can have a significant effect on product characteristics and thus can serve to strengthen and entrench not only competence in production, but linkages to customers and markets. It is important to note that these effects tend to take place over a significant period of time. They require an organizational environment and managerial skills that support the dogged pursuit of improvement, no matter how minor. The effects of a given regular innovation on competition are thus of less concern than the cumulative effects of a whole series of changes.

Some of these effects are quite direct and involve advantages due to improvements in the product's existing technology. Other effects, however, are more subtle and indirect; it is these effects that we explore in detail in section 3. Here it suffices to note that incremental change in process technology tends to both raise productivity, and increase process capacity, often through mechanization. This has the effect of increasing economies of scale and the capital required to compete. In addition, refinements in product design and in processes reinforce increases in scale economies by enlarging the amount of product variety that a given technology can support. Though the changes imposed by a given innovation in the regular mode may not be dramatic, a sustained pattern of such change can transform the business, altering substantively what must be done well to achieve competitive advantage.

2.4. Revolutionary innovation

Innovation that disrupts and renders established technical and production competence obsolete, yet is applied to existing markets and customers, is the fourth category in the transilience map and is labelled "Revolutionary". The reciprocating engine in aircraft, vacuum tubes, and mechanical calculators are recent examples of established technologies that have been overthrown through a revolutionary design. Yet the classic case of revolutionary innovation is the competitive duel between Ford and GM in the late 1920s and early 1930s.

While Ford's competitive moves with the Model A were based on imitative use of technology, the behavior of competitors was a different case entirely. For the industry as a whole, the mid-1920s marked the beginning of a revolutionary phase of innovation. Ford was focused on volume production of its established design, while GM began investing in new concepts in suspensions, body forming and transmissions. Studebaker and Chrysler contributed in important ways to advanced body, suspension and engine technology. In contrast to Ford's pursuit of volume and lower cost through the Model T, GM, Chrysler and other producers developed new designs in suspensions, bodies, and transmissions that redefined the nature of the automobile. The innovation that contributed more than any other to this change in competitive and technical emphasis was the closed steel body.

First marketed by Hudson in its 1921 Essex, the closed body made of steel was a clear departure from the open (no solid top or sides) wooden bodies then dominant in the market Chevrolet's Model K perfected the concept and GM introduced process changes that made the closed steel body an affordable feature in mass production vehicles. The innovation raised new criteria for automotive design – passenger comfort, room, heating and ventilation – and deepened and broadened the appeal of the product to the American consumer by making it more convenient, enjoyable and useable.

The closed steel body strengthened market linkages, but its impact on manufacturing was disruptive. Steel bodies depended on sheet metal forming technology rather than the craft skills of the wooden body maker, or the metal removal technologies used in engine and transmission production. What was required was new machinery, new skills in labor and management, and new relationships with suppliers. Moreover, the new technology increased minimum economies of scale, as giant presses and expensive dies were used to form the metal parts.

The closed steel body came to dominate the industry, and in so doing substantially altered the nature of competition. Along with other changes in technology it formed the basis for Chevrolet's sustained attack on Ford and the Model T. It weakened the relative position of small firms, at the same time that it changed the product characteristics on which competition had been pursued. Convenience, performance and comfort became the central theme in subsequent competition and technical innovation.

Not all innovations that fall in the revolutionary quadrant have a profound competitive impact. Some fail to meet market needs, while others encounter problems in production. And others, like Ford's 1932 V-8 engine, are poorly timed. In 1932 Ford introduced the Model 18 with a new V-8 engine. Through a stunning engine design and unique manufacturing process based on Ford's own casting and machining technology, the Model 18 offered a high performance engine in a popular price range. Here was an example of an innovative design with high technological transilience applied to an existing market position. In contrast to the Model A, product features were dependent on a technology in which Ford played a leadership role and in which the company had a sustainable lead. But the launch of the product was not well timed. In the depression era of 1932, a performance engine for the workingman was not a concept for the times. To make matters worse, the extra engine performance brought with it extra stress on reliability. Problems with knocking, thrown rods and burning oil were more visible in a period of tight budgets.

While the Model 18 enjoyed some market success, it did not captivate the market; its power for change was moderate. It thus seems clear that the power of an innovation to unleash Schumpeter's "creative destruction" must be gauged by the extent to which it alters the parameters of competition, as well as by the shifts it causes in required technical competence. An innovation of the most unique and unduplicative sort will only have great significance for competition and the evolution of industry when effectively linked to market needs.

3. The transilience map and industry evolution

Our application of the transilience map to the history of the auto industry shows that all four kinds of innovation have shaped the industry's development in subtle and diverse, but powerful ways. A similar conclusion as to the role of innovation emerges from detailed studies of a variety of other products and markets. The historical evidence suggests further, that innovations of a given type appear in clusters, and that the temporal pattern of innovation is closely linked to the overall evolution of the industry. The transilience map is thus much more than a simple categorization of technical change; it provides a framework within which one can examine the relationships among innovation, competition and the evolution of industries, as well as develop insight about the strategies of specific competitors.

Existing models of industry evolution posit a life cycle of development in which new products (and industries) emerge, are developed, defined, and mature [11]. Framed in terms of the transilience map, models based on the product life cycle, or the "fluid-to-specific" stage model of Abernathy and Utterback, are dominated by the transition from architectural to regular innovation. In fact, it is useful to conceive of the traditional life cycle as a development vector describing the firm's transition from one innovative phase to another. Our discussion of the different types of innovation, however, suggests that vectors of industry development may be richer and more varied than simple life cycle notions might suggest. In particular, the implicit (or sometimes explicit) biological life cycle metaphor seems to be misleading; the reversal of an older industry to embrace the emergence of revolutionary or architectural innovation may serve as the basis for renewal in its pattern of industry development. Kuhn's *The Structure of Scientific Revolutions* suggests that the advancement of science is characterized by long periods of regular development, punctuated by periods of revolution [12]. Historical evidence suggests that a similar pattern characterizes the development of technology. Furthermore, even within the traditional architecture-regular pattern, the role of innovation in competition may be more important, albeit subtle and indirect, than traditional approaches have assumed.

In this section of the paper we re-examine the regular phase of innovation, and its implications for the evolution of the industry's competitive environment. Our focus is on how regular innovation contributes to the embodiment of labor and managerial skills in capital equipment; to increasing rigidity in processes and products; and, somewhat paradoxically, to increased versatility in established designs. We then explore transitions out of the regular phase of innovation. Such moves result in technological ferment and form a varied set of complex but important strategic vectors of industrial development.

3.1. Regular innovation, capital embodiment and technical rigidity

The transition from architectural to regular innovation is often associated with the emergence of a dominant design in the product. With this the focus of innovation shifts from meeting emerging needs with new concepts, to refining, improving and strengthening the dominant design and its appeal in the market. It is important to recognize that this transition is but the search for a strategic advantage over competitors. Where advantage in the architectural phase rests on enhanced product performance that may be gained through creativity in linking new technology to latent needs, exploiting the advantage inherent in a dominant design demands a change in strategic orientation. It is for this reason that the transition to regular innovation can thus be seen as a "strategic vector" in the transilience map, leading out of architecture into a phase of refinement and improvement. The transition is thus not a move from one well defined "state" to another; it is more like charting a new path through an emerging environment.

In section 2 we noted some of the more obvious effects of regular innovation. But there are other subtle effects which a strategic vector in the regular direction may create. Consider, for example, the effects of typical improvements in processes. Innovation of this sort is often little more than the act of taking the skill that workers or managers use in performing tasks and embodying it into the design of a machine. The innovation may replace elements of the task, or eliminate the need for the worker (or manager) entirely. Examples of such embodiment are prevalent in the three innovations in the early auto industry as listed in table 2: mechanized welding, moving assembly lines, and enamel finishes.

Electric welding of metal parts was used before welding was mechanized. However, reliable performance in high-volume applications was not achieved until Ford developed a mechanical seam welder that could be operated by an unskilled operator. This was an important early step in the development of extensive welding in the body-building process. It is important to note, however, that the automatic welding device became linked to a particular model. In order to promote efficiency, its design was so specialized that, for example, an automatic welding machine of Model A vintage was not usable on the next model. Thus, the embodiment but not the concept of the technology became vulnerable to change.

Mechanized welding illustrates the embodiment of labor skills and the "shaping" effect that accrues from incremental innovation as it renders the process for a given product more specific and rigid in nature. The moving assembly line illustrates the same phenomenon in managerial skills. Just before the moving assembly line was adopted in January of 1914, Ford had developed a method of assembly involving team scheduling with stationary product and roving teams that offered the same degree of work force specialization as the moving assembly line. The team method, however, required much more careful supervision and a close eye on inventory control. The moving assembly line in contrast, simplified the supervision and inventory management problems in one stroke through the imposition of a novel conveyor technology. This made the task of management much less demanding although not necessarily more efficient – if the quality of management was otherwise excellent. With less demanding tasks, the range of experience to which the supervisor was exposed became limited. The moving assembly line decreased opportunities for training managers to cope with nonstandardized production such as small-scale stall build systems. Small lot or stall build became an anathema to the industry. As with the welding innovation, the innovation left the industry more rigid and limited in the range of unanticipated change it could accommodate.

A third case, the adoption of new finish coatings on steel body parts, illustrates the role of regular innovation in achieving mass production. The Model T was initially offered only in black because a satisfactory colored finish required repeated sanding, rubbing and polishing operations between many successive coats of finish. By one estimate, 106 days were required to produce a car body with a superior color finish. Most of this time was in drying. Such skill, care and time were required that mass production was unthinkable. The innovative new application and finish technologies of the 1920s changed all of this by requiring only that operators perform short duration tasks that were quite teachable, that demanded less training, that were machine paced, and that involved much less inventory. The innovation made possible and reinforced mass production of colored bodies. The new technique could not be scaled down very well to handle low production rates and in this sense, the innovation raised minimum economies of scale.

What Ford gained from capital embodiment was an ability to more rapidly expand its capacity in the face of burgeoning demand and a limited supply of skilled labor. It was easier to duplicate machines than skilled labor and management in a tight labor market. Furthermore, the demand for new equipment embodying labor and management was not satisfied through internal development alone. Outside suppliers played a significant role in producing the volume of machinery that Ford required.

Recent experience in the semiconductor industry underscores the close link between capital embodiment and appropriability. In new industries that are based upon innovative technologies, the skills which are critical to competitive success initially are usually not capital embodied. Entry in this phase involves much more than the acquisition of capital assets; witness the experience of many large firms who tried to enter the semiconductor industry during its formative years. There is evidence that scarcity of technical and management talent was the single most important reason that large vacuum tube producers failed to buy their way into a successful semiconductor business during the 1960s and 1970s [13]. These skills in management and technology were not appropriable through traditional means of merger or capital acquisition. Logically under these conditions the most important mode of competitive industrial propagation was by spin-off.

3.2. Regular innovation and market-niche versatility

Regular innovation that embodies skills in equipment serves to increase minimum economies of scale and to make established processes more specific and rigid. Yet, somewhat paradoxically, regular innovation may also increase the versatility of technology. Once again, the development of the Model T provides a fruitful example.

At the end of its life, the Model T was a far different car than its early predecessor. The car of 1926 started electrically, had electric lights, a closed colored body, and sold for less than one half the earlier price. Furthermore, it was much easier to use and appealed to a much wider range of market segments. As the grand old product evolved it simultaneously became more versatile and appealing to a broad range of market segments, while the supporting productive unit became more rigid and vulnerable to unanticipated change. This expanded versatility is not just a definitional distinction. It may be observed in the very specific detail of engineering data on the product and process technology. The evidence shows that Ford's engine line was functionally broadened through innovation so that it could more robustly accommodate a variety of market segments with less and less actual mechanical variety [14].

The technology of early automotive engines was not well developed. In order to power a large, expensive car a large elaborate engine was needed. Since Ford in the early years served many market segments (Model K was the largest and most expensive line; Models A, B and C were the less expensive and smaller products) a line of engines was needed that could meet a wide range of customer demands. Engine variety as a function of market segmentation is illustrated in fig. 2 which compares the range of cubic inches of displacement and delivered horsepower in Ford's engine line from 1903 to 1908. The data show that large variation in engine size (353 CID), yielded the small, but critical difference of 32 horsepower in the market.

Over time, incremental advances in both product and process technology not only improved the engine's performance, but also increased its versatility in meeting market needs. Incremental innovations like dynamic balancing reduced vibration and prolonged operating life; constant temperature inspection rooms led to greater precision in manufacturing and therefore a wider dynamic range of performance in aspects like speed (r.p.m.), compression and horsepower per unit size. The rubber engine mount, widely adopted in the 1930s, broadened the appeal of small cylinder count engines. Before its use, smoothness of ride was achieved largely by high cylinder count engines like the V-12, or even the V-16. Such engines were associated with speed, power and prestige, but they also served to guarantee smooth operation. The advent of the simple rubber engine mount in a V-8 design eliminated the need for great mechanical variety since it isolated the transfer of vibration to the chassis, without adding more cylinders.

Increased technical versatility is an important dimension of regular phase innovation, but it may also be the basis for a strategic thrust into niche creation. The essence of increased versatility is greater understanding of the possibilities in the

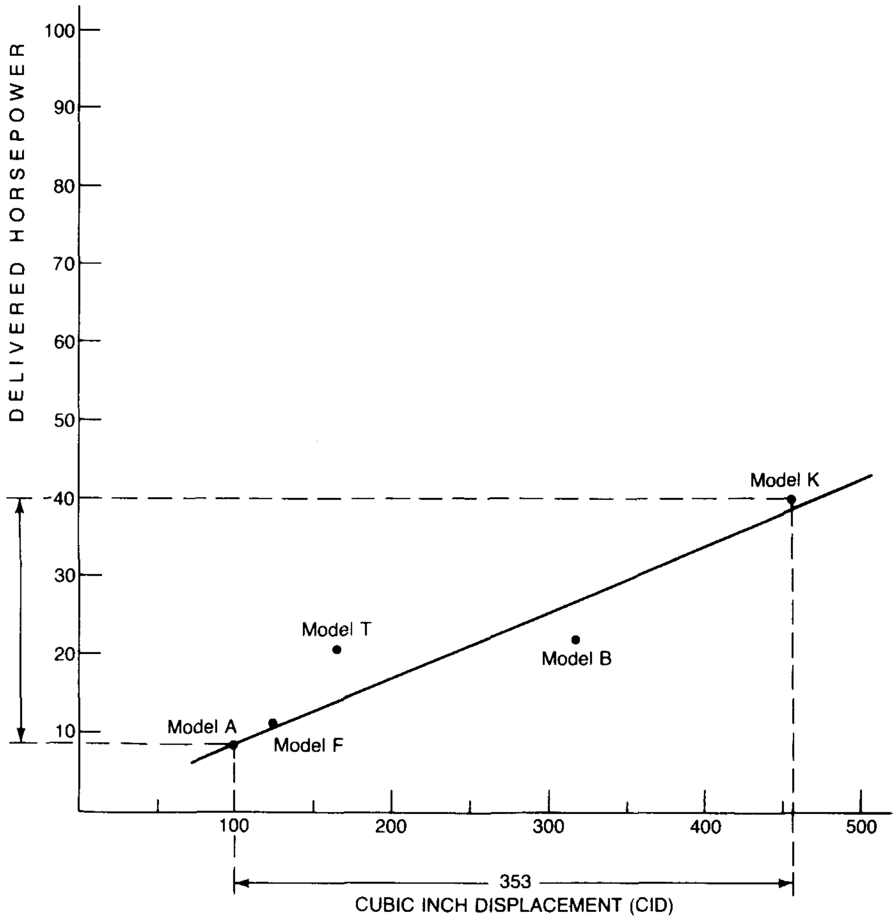


Fig. 2. Relationship between mechanical variety (CID) and performance (HP) in Ford engines 1903–1908.

technology and the implications of alternative refinements. Enhanced technical insight and understanding may provide the design change required to offer a new product configuration, or a different mix of performance characteristics that meets an identified new set of customer needs. This seems to have been the case with the Model A in 1927, with the creation of "muscle" cars in the 1950s, and affordable sports cars (e.g. Mustang) in the 1960s.

Niche versatility was characteristic of automotive development through periods of regular innovation and later in the creation of market segments and niches. The cumulative effect of numerous innovations on Ford's engine line from 1900 to 1958 is depicted in fig. 3. In this figure the earlier trend in market variety versus mechanical variety is extended for groups of major Ford engines by decades. The increasing market-niche versatility is evident in the counter clockwise rotation of the lines indicating the relationship between mechanical variety and horsepower. By the 1950s a difference of 245 horsepower was provided by a range in mechanical variation of a little over a 200 cubic inches of displacement. This compared to a variation of 32 horsepower for a large 353 cubic inch displacement in the early 1900s.

The significance of a trend toward greater market-niche versatility for our purposes lies in its implication for innovation. As the versatility increases there is less need for novelty and technical variety in meeting a variety of market needs. In a sense, incremental innovation is self-limiting, just as Gilfillan, an early scholar on the subject observed many decades ago [15]. As long as market demands are anticipated, as long as they are consistent with embedded experience, a technology that has been refined and improved will be rela-

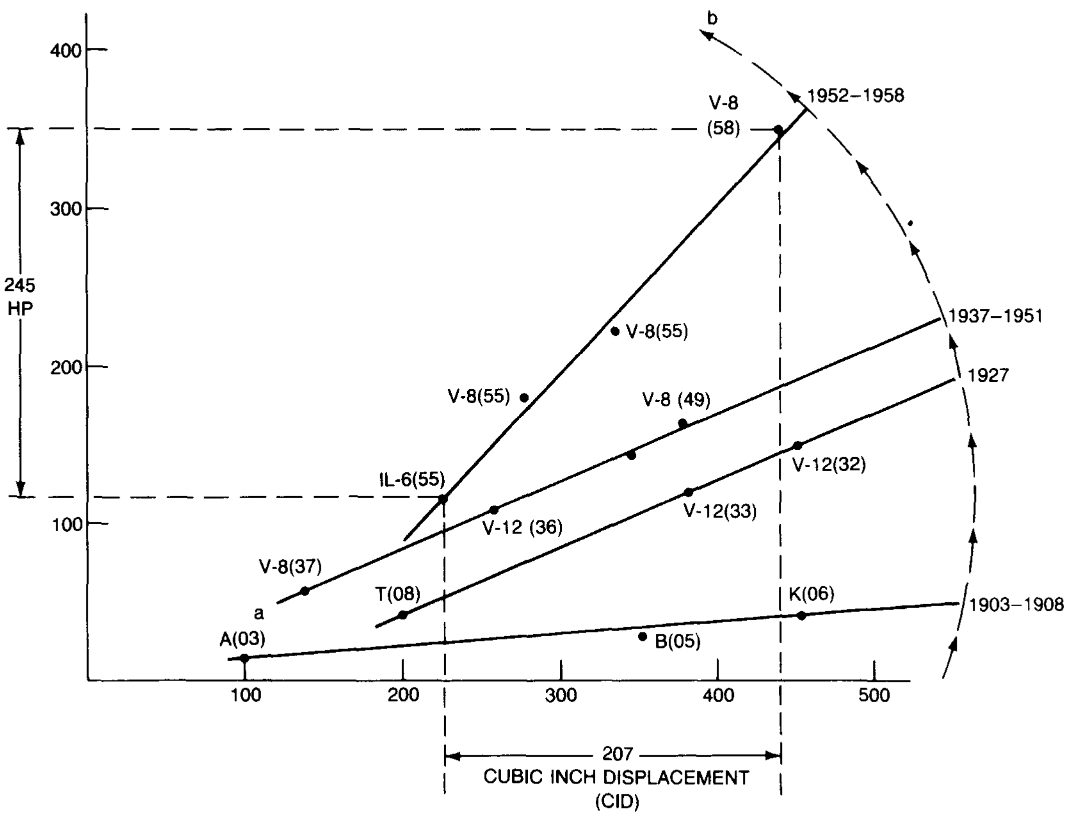


Fig. 3. Trends in market-niche versatility for the Ford engine line 1903–1958.
[a] The number in parenthesis is the year in which the engine model was introduced.
[b] Rotation (the dotted line) shows a decrease in the ratio of mechanical variety needed to deliver a given range of performance in horsepower from the 1903–1908 era to the 1952–1958 era.
Source: W.J. Abernathy, *Managerial Dimension of Technological Trends* (unpublished, 1975).

tively robust in meeting them.

These observations on evolutionary adaptation in an industrial unit are related to ecological concepts about development and dominance of biological species within their "niche" in the environment. As the product and process technologies evolve and develop, they become more robust in the way they accommodate the full range of variety in the existing environment. Like the tree that develops an extensive root system to weather the dry seasons it must occasionally face, management refines and perfects a product over time to better accommodate the range of variation in the market. Yet a product and process technology that becomes more highly organized and efficient in the way it meets established requirements, it also becomes more vulnerable to sudden and unanticipated variations in the environment. The highly productive, efficient and developed product unit is also more vulnerable to economic death.

3.3. Innovation and reversals in development

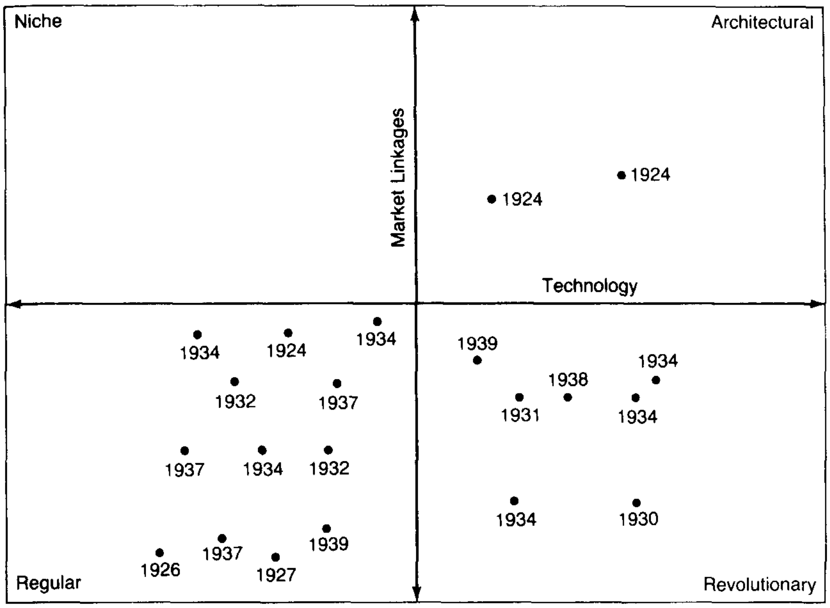
Sustained periods of regular innovation are predicated on a stable relationship between the needs and preferences of customers and the design concepts in the technology. Regular innovation thus follows the emergence of a dominant design. But it also reinforces the dominance of that design through improved performance, reliability and lower cost. As the technology develops in the regular phase, the preference-technology nexus inherent in the dominant design strengthens as it grows more complex. If, however, the relationship between customer demands and technical characteristics begins to break down, if new technical options emerge, or if the range of demands begins to strain the ability of the existing designs to meet them, firms may find a move away from regular innovation advantageous.

We have in mind something more than a move to exploit new market niches. What we want to consider is the possibility that changes in the environment may create the opportunity (or the necessity) for a strategic vector out of the regular mode of innovation, into the revolutionary or architectural phase. A strategic thrust of this sort implies the re-emergence of a kind of innovation – new concepts, departures from existing designs – and a degree of technical variety and ferment that is more like the early stages of an industry's development. In contrast to the typical "birth-growth-maturity-decline" pattern of development, the transilience map thus suggests the possibility of "de-maturity" [17].

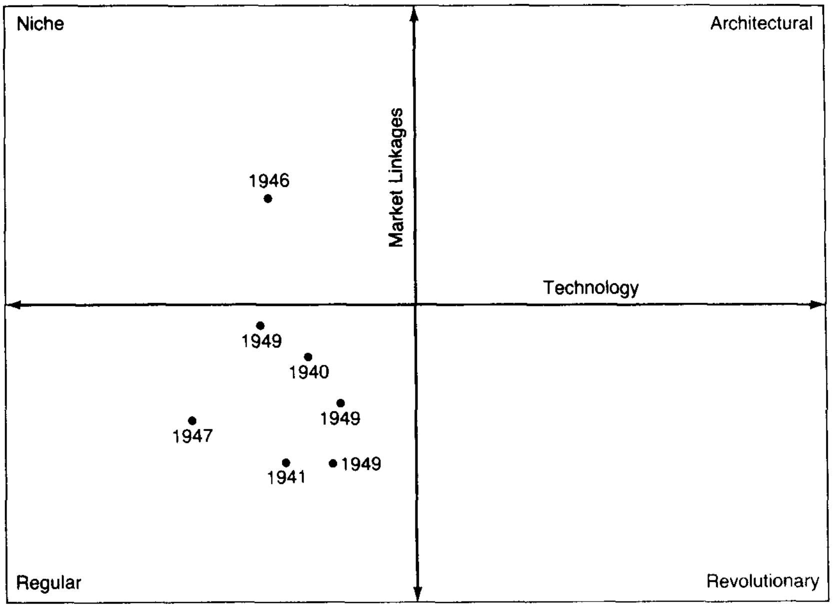
There are three kinds of changes in the industrial environment that may create the conditions for de-maturity. The first is new technical options that open up possibilities in performance or new applications that the existing design concepts could meet only with great difficulty or not at all. These options may come through research and development from within the industry, or they may be the basis for an invasion by competitors from a related field. The second impetus for dematurity may come from changes in customer demands. Whether through changes in tastes, or through changes in prices of substitutes or complements, new customer demands may impose requirements that can best be met with new design approaches. The third source is government policy. Regulations imposed on an established industry, for example, may set technical requirements or demand performance standards that favor revolutionary or architectural strategic development. De-regulation may have the same effect.

The impact of the closed steel body on the auto industry of the 1920s illustrates the possibilities of de-maturity and the critical elements of a successful strategy in that environment. In section 3 we noted the emphasis in technical development on comfort, convenience and ease of operation that followed the new body technology. One of the first that exploited the opportunities that a new direction in technology presented was the Chrysler Corporation. The company was founded in the 1920s and in its rise one can see the consequences of a well executed strategic thrust into revolutionary and architectural innovation.

Figure 4 shows the position of Chrysler innovations from 1924 to 1949 on two transilience maps; the first covers the period 1924–1939, while the second covers 1940–1949. The position of each point on the map is derived from a qualitative assessment of the impact of the innovation. The assessment was based on historical evidence of the changes required to implement the innovation. The first map (top half of figure) shows Chrysler's departure from the pattern of innovation that had characterized the industry in the Model T era. From 1930 to 1939 Chrysler introduced several innovations in carburetion, body design, transmis-



I.
Chrysler
1924–1939



II.
Chrysler
1940–1949

Fig. 4. Transilience maps of Chrysler innovations [a]

[a] For a definition of the dimensions of the map see fig. 1.

Source: W.J. Abernathy et al., *Industrial Renaissance* (Basic Books, New York, 1933), Appendix D, pp. 155–77.

sions and chassis construction that departed from established practice. These changes in technology were embodied in models designed for existing customer groups and existing channels, and thus have been placed in the revolutionary quadrant. Chrysler also introduced refinements in noise and harshness characteristics, seats, and dashboards that appear in the regular innovation category. Chrysler's regular innovation and those that were more revolutionary reinforced one another. The emphasis in both cases was on comfort and convenience, power and smoothness of ride. Both kinds of innovation helped to build and then to strengthen Chrysler's appeal in the marketplace, but it was the significant revolutionary changes that gave Chrysler its distinctive character, and its competitive advantage.

The contrasts between Ford and Chrysler, and between the Chrysler of the 1930s and the Chrysler of later years are instructive. Faced with similar market developments and technical possibilities, Ford's strategic thrust (as evidenced in the Model A) was to define the family car on the basis of imitative product technology, and to push forward with innovations in production processes. Almost all of Ford's innovations in the 1930s involved processes, and few of those resulted in product characteristics valued in the market. Thus while GM and Chrysler (and others) were at work on new concepts in suspensions, brakes, transmissions, and bodies, Ford's development efforts were largely focused on the cost of manufacture.

Chrysler's strategy of new design concepts and thus of flexibility in product characteristics was highly successful in the decade of the 1930s; by the end of the decade Chrysler had passed Ford in market share. In the 1940s, however, the second transilience map (bottom of Fig. 4) shows clearly that Chrysler shifted its focus to incremental technical change in both the regular and market niche modes. This shift was consistent with the emergence of a new dominant design – the "all-purpose road cruiser" – in the early 1940s, and subsequent efforts to segment the market. Although Chrysler was a significant participant in subsequent years, its market share declined as the rate of technological change in the product diminished. Product engineering remained a central element in the Chrysler approach, but the kinds of changes introduced offered little that was unique or distinctive. In contrast to its heritage as a pioneer in new design concepts, the Chrysler of the 1950s and 1960s was caught between two strategies: too small and inefficient to compete on cost; not innovative enough to create a technology-based differentiation.

4. Managerial implications and conclusions

This paper has presented a new way of assessing the competitive significance of an innovation – the transilience map. Each quadrant in the map represents a different kind of innovation, and tends to be associated with a different competitive environment. Moreover, because the nature of change imposed on the firm is so different, the framework implies that the successful persuit of different kinds of innovation will require different kinds of organizational and managerial skills. The transilience map may thus illuminate the managerial environments required to nurture innovation and technical progress in each mode. Much further research remains to be done, but our work to this point suggests a number of working hypotheses.

In the architectural phase management must encourage the creative synthesis of information and new insight into user needs with information about technological possibilities. Architectural innovation thus demands attention to the management of creativity with a keen insight into business risk. Unique insights about user needs, usually accrued through personal experience must be combined with an ability to see the application of technologies in a new way. The task is one of constantly scanning for technological developments and unmet market needs, and orchestrating the creative, first-time combination of resources.

In contrast, timing is the essence of management in the niche creation phase. The technology is generally available; the key skill is sizing up new market opportunities, and developing a product package that exploits them. Management must nurture quick-footed capability for getting into the market before competitors enter the same niche and destroy profitability. Under these conditions. manufacturing must be quick and responsive, insuring timely delivery, responsive service and adequate capacity for a quick buildup.

In the regular mode, methodical planning and consistency are key management factors. Stability of product design and sources of materials are needed to support directed technological progress, engineering improvements, market refinement and continuing process development. Management may need to buffer the organization against supply disruptions or other environmental changes. The idea is to achieve volume production and use scale economies to lower costs and improve products. Every opportunity must be taken to advance quality, improve product features, break bottlenecks in production, and foster process innovations that reduce scrap and increase yields. This is the world of the administrator, and the functionally oriented engineer.

The revolutionary mode of innovation is dominated by "technology push". Management must be capable of sustaining a consensus about long-term goals through investments in new technology and innovation. Here the task is to focus possible unruly technical talent toward specific markets and to marshal the financial resources for this purpose. Good technical insight is needed to break established conventions and foster close collaboration between product designers, process designers, and market planners. The climate must be one that encourages a sense of competitive assault.

The hypotheses about managerial environments and the historical analysis of the auto industry suggest a number of questions and directions for further research. The transilience map itself, of course, requires further study through application in other industries. Detailed examination of the technological and competitive development of other industries should focus both on testing the ideas discussed here, and refining and extending them. Work along these lines is underway in aircraft and semiconductors.

A particularly fruitful area for further analysis is the notion of strategic vectors, and associated industry transitions. The differences in organizational environments in each mode of innovation implies that a transition from one phase to another may pose a significant challenge to established firms. This suggests the need to examine the impact of innovation on market structure during periods of transition, as well as implications for management. Historical evidence suggests that the creation and development of technology-based industries leads the industry from quadrant to quadrant. It is at these points of transition that originating firms exit and are replaced by new firms better able to manage in the new mode. On the other hand, firms like Ford and Douglass Aircraft have managed to make the transition. The nature of transitions, and the determinants of survival deserve additional attention and analysis.

The differences across types of innovation also have implications for the management of technology at a given point in time. While a firm may have a dominant orientation, it is likely that the firm will face the task of managing different kinds of innovation at the same time. While one part of the product line may be in the regular phase of development, the firm may try to introduce a revolutionary development in another, and may try to develop new niches in a third. Whether firms ought to manage in that way, and if so, how to do it seems an important area for further work. Pursuit of these issues will require an examination of the impact of market structure and competitive rivalry on the different kinds of innovation.

Notes and references

[1] See for instance: M. Abramovitz, Resource and Output Trends in the United States since 1870, *American Economic Review* 46 (1956) 4–23; Robert Solow, Technical Change and the Aggregate production Function, *Review of Economics and Statistics* 39 (1957) 312–30. S. Kuznets, *Secular Movements in Production and Prices* (Houghton Mifflin, Boston, MA, 1930).

[2] For example, F.M. Scherer, *Industrial Market Structure and Economic Performance*, (2nd edition, Rand McNally, Chicago, IL, 1980); Joe S. Bain, *Barriers to New Competition*, (Harvard University Press, Cambridge, MA, 1956).

[3] See, for example, T. Burns and G. Stalker, *The Management of Innovation* (Tavistock Publications, London, 1961); U.S. Department of Commerce, *Technological Innovation; Its Environment and Management*. A report by the panel on innovation, Robert Charpie, Chairman (U.S. Government Printing Office, Washington, DC, January 1967); Also John Jewkes et al., *The Sources of Invention* (Macmillan, London, 1960).

[4] Michael E. Porter, The Technological Dimension of Competitive strategy, in: R. Rosenbloom (ed.) *Research on Technological Innovation, Management and Policy* Vol. 1. (JAI Press, Inc., Greenwich CT, 1983) pp. 1–34. Richard S. Rosenbloom, Technological Innovation in Firms and Industries: An Assessment of the State of the Art, in: P. Kelly and M. Kranzberg et al. (eds.) *Technological Innovation: A Critical Review of Current Knowledge* (San Francisco Press, San Francisco, 1981), pp. 215–30. Nathan Rosenberg, *Inside the Black Box* (Cambridge University Press, Cambridge, 1982). Richard R. Nelson and Sidney G. Winter, *An Evolutionary Theory of Economic Change* (The Belknap Press of the Harvard University Press, Cambridge, MA, 1982).

[5] Rosenbloom, Technological Innovation in Firms and Industries. See [4].

[6] Although the three types of competence are closely related, it seems useful to make distinctions among them. In the first place, they may play somewhat different roles in determining the firm's position, and innovation may affect them in different ways. Furthermore, the competencies are acquired and developed in very different ways. Material resources, and some human skills are often available through established markets. But some skills and some types of knowledge are specific to the firm and must be developed internally through experience. Whether through market transactions or through internal development, the

acquisition of resources, skills and knowledge is costly and especially in the case where internal development is required, may take much time.

[7] Joseph A. Schumpeter, *The Theory of Economic Development* (Harvard University Press, Cambridge, MA, 1934).

[8] *Timex Corporation*. Harvard University Graduate School of Business. Case No. 9-373-080 (1977).

[9] W.J. Abernathy and J.M. Utterback, Patterns of Industrial Innovation, *Technology Review* 50 (7) (June–July, 1978). T. Burns and G. Stalker, *The Management of Innovation* (Tavistock Publications, London, 1961). *Ibid.*, p. 19. Also John Jewkes et al., *The Sources of Invention* (Macmillan Co., London, 1960).

[10] Examples cited in this section as they relate to the automobile industry are not referenced individually. The background of this section draws on underlying research published in William J. Abernathy, *The Productivity Dilemma: Roadblock to Innovation in the Automobile Industry* Johns Hopkins University Press, Baltimore, 1978); and W.J. Abernathy, K.B. Clark and A.M. Kantrow, *Industrial Renaissance: Producing a Competitive Future for America* (Basic Books, New York, 1983).

[11] We refer to the "technology life cycle" concept as a representation of the changes in infrastructure within the firm that support a given state of technology, in particular, see W.J. Abernathy, *The Productivity Dilemma* [10]. Closely related is the International Product Life Cycle, see L.T. Wells (ed.) *The Product Life Cycle in International Trade* (Division of Research, Harvard Graduate School of Business Administration, Boston, 1972).

[12] T.S. Kuhn, *The Structure of Scientific Revolutions* University of Chicago Press, Chicago, 1962).

[13] J.E. Tilton, *The International Diffusion of Technology: The Case of Semiconductors* (Brookings Institution, Washington, DC, 1971); and D.C. Mueller and J.E. Tilton, R and D Cost as a Barrier to entry, *Canadian Journal of Economics* 2 (4) (November 1969) 570–579.

[14] These trends were developed and reported in an early draft of the *Productivity Dilemma* by W.J. Abernathy, Managerial Dimension of Technological Change: Innovation and Process Change in the U.S. Automobile Industry (1975).

[15] C.S. Gilfillan, *The Sociology of Invention*, (MIT Press, Cambridge, MA, 1935).

[16] The analogy with ecological models is interesting; see for instance S.J. McNaugton and L.L. Wolf, Dominance and the Niche in Ecological Systems, *Science* 167 (3915) (January 9, 1970) 131–139.

[17] The nation of "de-maturity" is discussed in W.J. Abernathy, K.B., Clark and A.M. Kantrow, *Industrial Renaissance* (Basic Books, New York, 1983). See also K.B. Clark, Competition, Technical Diversity and Radical Innovation in the U.S. Auto Industry in: Richard S. Rosenbloom (Ed.) *Research on Technological Innovation, Management and Policy* (JAI Press, Greenwich, Conn., 1983).