THE FUTURE OF THE AUTOMOBILE

A DYNAMIC APPROACH TO THE PROBLEMS
OF THE AUTOMOBILE INDUSTRY

by
William J. Abernathy
Joan Dopico
Burton H. Klein
James M. Utterback

Research Paper
International Policy Forum
Eagle Lodge, Pennsylvania, U.S.A.
28 June - 1 July 1981

AN INTERNATIONAL PROGRAM
COORDINATED BY THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CENTER FOR TRANSPORTATION STUDIES

CENTER FOR INTERNATIONAL STUDIES

Future of the Automobile Program

ALAN A. ALTSHULER, CO-DIRECTOR
DANIEL ROOS, CO-DIRECTOR
ROBERT P. GREENE, EXECUTIVE OFFICER

BUILDING W76
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS 02139
(617) 253-8540
TELEX: 921 473 MIT CAM

June 1981

US-E-81-3

A DYNAMIC APPROACH TO THE PROBLEMS OF THE AUTOMOBILE INDUSTRY

by
William J. Abernathy
Joan Dopico
Burton H. Klein
James M. Utterback

Research Paper
International Policy Forum
Eagle Lodge, Pennsylvania, U.S.A.

28 June - 1 July 1981

Center for Policy Alternatives
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Center for Policy Alternatives
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

A PROPOSAL FOR POLICY ORIENTED RESEARCH ON THE AUTOMOBILE INDUSTRY

June 23, 1981

William J. Abernathy
Burton H. Klein
Joan Dopico
James M. Utterback

A PROPOSAL FOR POLICY ORIENTED RESEARCH ON THE AUTOMOBILE INDUSTRY

This paper is concerned with two areas of policy-oriented research: (1) research that will lead to a better understanding of public measures that will or will not contribute to a viable automobile industry; and (2) research concerning actions that automobile firms can take that will or will not contribute to their dynamic stability--that is, their ability to evolve smoothly in the face of new circumstances.

An understanding of these two questions first requires a clear understanding of the concept of dynamic stability, for this concept is directly opposed to the common wisdom. Common wisdom has it that a stable firm is one in which each department is as predictable as the planets. The dynamic argument, however, states that a firm can assure its predictability in the large only by being quite unpredictable in the small--that is, by a willingness to make, or borrow, new discoveries. Thus, the essential difference is that the static concept assumes that knowledge will unfold gradually with no real surprises, while the dynamic concept makes no such assumptions. These two concepts, therefore, require very different types of behaviors from firms.

Furthermore, it is important to cover the effects of both public and private policies, for the two are highly interrelated. For example, certain public actions can rob firms of their dynamic stability. However, firms that aim only at predictability in the small can create serious unemployment problems which magnify the need for public action.

Finally, the recommended research covers a wide range of areas: from a better understanding of the ability of automobile firms to deal with competitive negative feedback (with the adversity that results when a more promising new model is able to attract customers away from a less promosing model) to dealing with the problems of chronic unemployment. At the same time, the research has a common underlying theme: taking such public action as is necessary to promote a more viable automobile industry than currently exists.

This paper initially will outline the dynamic theory of how technological progress develops, for such a theoretical structure is necessary for understanding the current predicament of the U.S.

automobile industry and the broad directions a return to dynamic stability might take.[1] The paper will then go on to discuss the more specific public and private policy issues related to the automobile industry. On some of these issues, we feel that quite satisfactory general answers already have been provided through previous research, but we also feel that there many important issues that still require a good deal of further work.

CHARACTERISTICS OF A DYNAMIC INDUSTRY

The characteristics of a dynamic industry are: (1) rivalry between firms to generate better, or less expensive, alternatives; (2) a high degree of decentralization in organizational structure; and (3) a high degree of flexiblity in making use of new technological ideas.

The General Role of Rivalry

Static economists are concerned with competition as it affects the allocation of resources in an unchanging world. Dynamic economists are concerned with rivalry as it provides ever-better technologies and thereby changes the world. To be more specific, "rivalry" is herein defined as competition to generate better quality or less costly alternatives. Thus, the principal difference between this dynamic competitiveness, and competition as described in static economics, is that when it is working, dynamic rivalry generates both positive and negative feedback, while static competition generates only positive feedback (i.e., the famous "hidden-hand").

Business people will always tell you that they are engaged in fierce competition, whether it involves making a trivial technological change or a significant advance. In this paper, however, we are concerned only with the latter type of competition. Products with significant improvements are constantly superceding older products--that is, at the time the more successful firm is experiencing "prosperity," the less successful one will be experiencing recession. This adversity that the less successful firms suffer is described as "hidden-foot feedback."

Hidden-foot feedback affects firms in two ways. First, it promotes a highly decentralized R&D operation in which the response to negative feedback can be quick and effective. Second, it assures that firms will be concerned with long-run, rather than short-run, profit goals. Conversely, when negative feedback is absent, firms tend to become highly centralized and unadaptive--an almost inevitable result of operating in an environment in which changes in knowledge occur almost imperceptibly.

Because rivalry forces firms to take the actions of their rivals into active consideration, it performs two important economic functions:

1. It acts as a stimulus to productivity gains.

2. It acts as a deterrent on wage increases and restrictive union practices.

How Rivalry Stimulates Productivity Gains

The immediate effect of rivalry is to stimulate firms to ask important questions in terms of developing better quality or less expensive products; when this feedback is no longer generated, firms tend to glory in past technological achievements and leadership ceases to be entrepreneurial. When firms engage in price competition (or in quality competition with sharp price constraints), the result is a strong incentive for productivity gains. If firms are to engage in such competition without suffering losses, they must find ways to reduce costs by developing less expensive products, making process discoveries, or searching for ways to increase the slope of learning curves. However, as we will see, this method of operation implies a highly flexible procedure for making the transition from R&D to production.

Let us assume that when one firm in an industry gets a jump on its competitors, the others must pay an "average tax" of fifteen percent measured in terms of loss of sales, market shares, and profit rates. How does this affect the rate of progress in an industry? Although space does not permit a full development of the dynamic argument, the general idea is relatively simple:

1. A significant hidden-foot "tax" eventually forces firms to allocate a significant proportion of their R&D resources to high-risk projects.

2. When firms do not aim for incremental advances, both luck and the fact that they will not all be taking risks simultaneously will influence the outcome; as a consequence, we can predict wide differences in their degree of success (e.g., 30 to 40 percent differences in the per-seat-mile cost of commercial airplanes).[2]

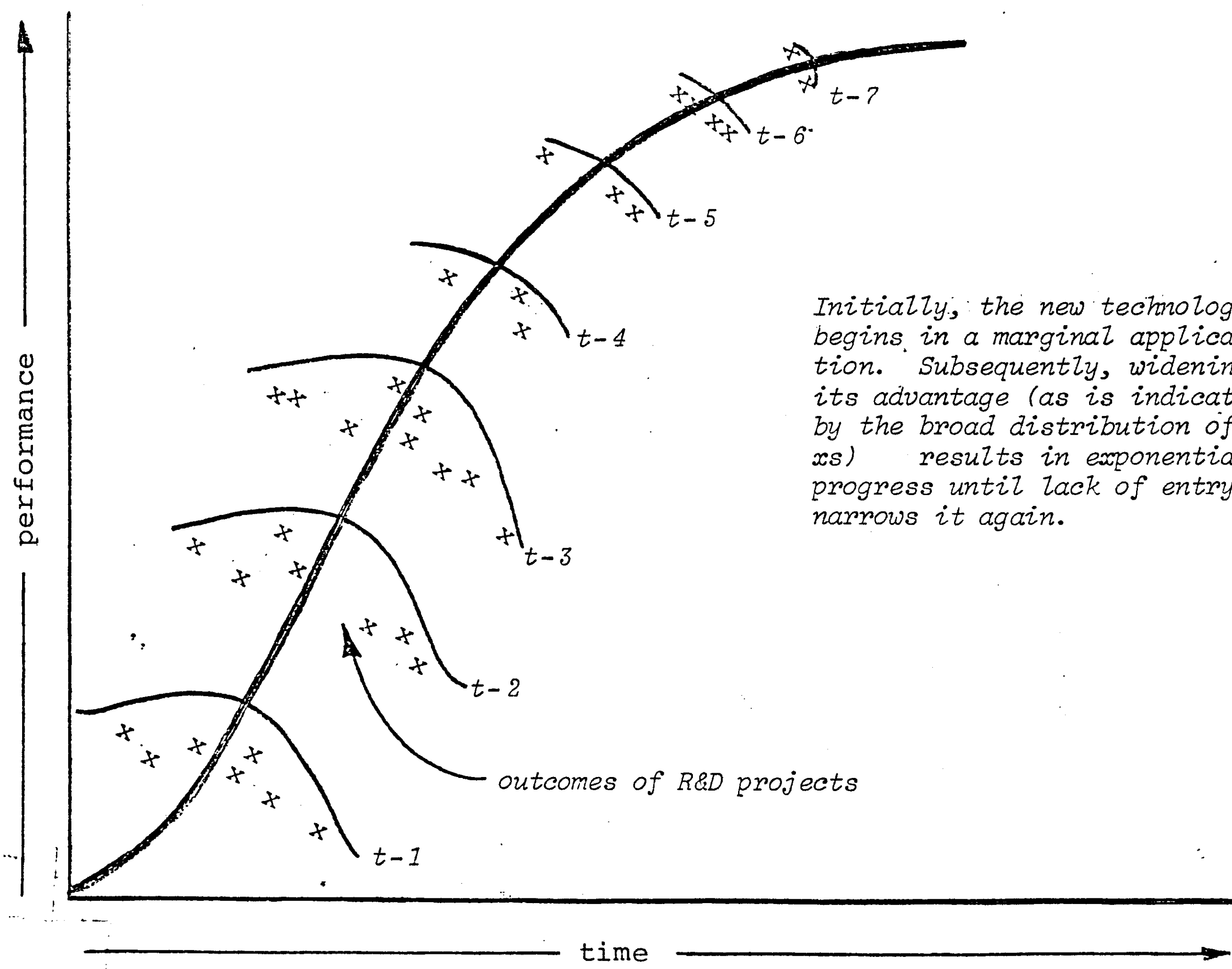
3. It also can be predicted that under such circumstances, progress will advance at an exponential rate. In other words, it can be shown that there is a positive mathematical relationship between the degree of risk-taking (as measured by the width of the revealed distribution) and the rate of progress (Figure I).[3] Consequently, when the players continually cooperate by imposing risks upon each other (thereby keeping each other at peak dynamic efficiency) the path will be exponential. Furthermore, it can be shown that there is a critical number of "experiments" that need to be performed during each time period to keep the distribution wide, and as this number declines so will the probability of continuing exponential progress. At the same time, it is important to remember that not all new automobiles and automobile engines will be equally successful; the laws of chance require a diversity of experiments to keep a dynamic process in motion. Consequently, with ten such experiments in a three or four year time period we will have high confidence exponential progress; with five experiments the predicted rate will decline; and with only one or two it will rapidly decay. These are conservative estimates that allow for varying degrees of success--but not for slackers.

It is apparent that only continuous feedback can assure this dynamic result. This need for continuous feedback, in turn, assumes that newcomers will be entering the industry. Consequently, when entry declines, firms will be less pressured to bring about significant advances and will recruit more and more managers from within the industry. This practice will not only foster a common language, thereby narrowing the distribution still further, but, in addition, a lack of diversity among managers can provide a major obstacle when it comes to dealing with uncertainty.

When the distribution narrows, insiders will claim that all technological possibilities have been exhausted. However, the point at which a technology runs into sharply diminishing returns depends on how narrowly or broadly it is defined. For example, as Utterback has shown, startling improvements were made in a number of cases (ice-making, gas lighting, telegraphy, cotton textiles, etc.) by broadening the definition

Figure I

THE S CURVE AS DETERMINED BY THE AVERAGE OUTCOME IN VARIOUS TIME PERIODS



of the older technology when it was challenged by a newer one.[4] Similarly, foreign penetration of American markets usually occurs because foreign firms have found ways to broaden the definition of the technology (e.g., front-wheel-drive cars with transverse mounted engines, Japanese steel, German and Japanese cotton textile machinery, etc.).

This is not to say that the narrowing of a distribution never reflects a genuine lack of technological opportunities. But it is to say that, more often than not, firms become so structured that they only search very narrowly. Indeed, it is this structuring that critically limits progress: the more specialized firms are, the more narrowly they tend to search for new opportunities.

It is important to note that this entire picture assumes that during the period the technology is developing, there are no sharp changes in the outside environment: in consumer preferences, in the availability of inputs, in competition from other industries, or in competition from foreign firms. In fact, the mathematics warns us that if these assumptions do not hold, the narrowing of the distributions will not result in a greater degree of predictability, but, rather, in a greater degree of unpredictability. In other words, the closer we move toward a static equilibrium, the closer we move toward chaos if these conditions do not hold.

Rivalry As A Constraint on Labor Union Practices

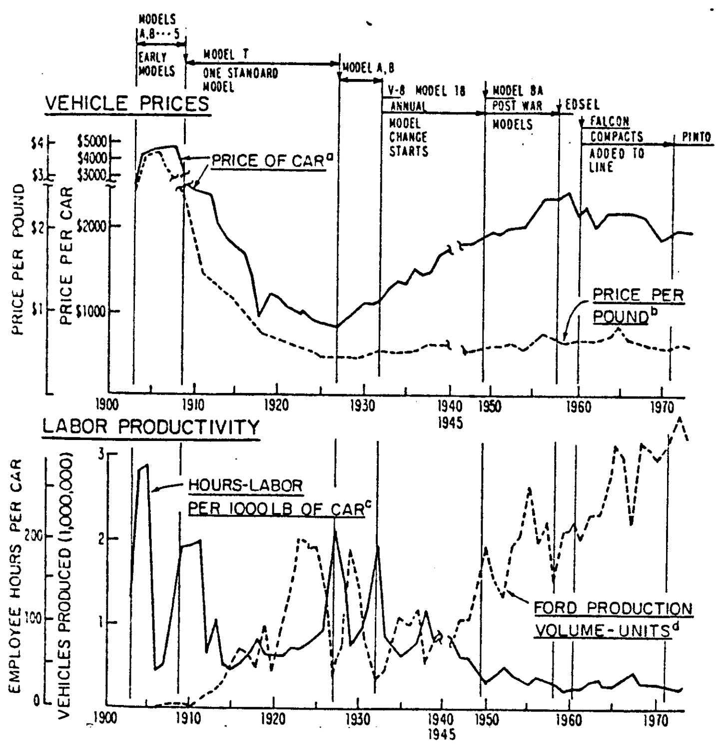
The second major role of rivalry is that it acts as a constraint on wage increases: workers that press for relatively rapid wage increases in a rivalrous industry will find that their demands have caused drastic unemployment. Thus, it is no accident that during the period 1958-1976, the high productivity manufacturing industries (i.e., those whose productivity performance was one standard deviation above the average during the first half of that period) experienced no more rapid increases in wages (despite their better productivity performance) than the lower productivity industries.[5] It is no accident that in these industries prices rose by less than they did in the economy as a whole. Thus, while it has become fashionable to blame everything on labor unions, the fact is that the absence of rivalry and unstatesman-like behavior of union leaders go hand in hand--e.g., the steel industry, the airline industry prior to deregulation, or, much earlier, the U.S. railroad industry.

Relationship of the Work of Abernathy and Utterback to the Work of Klein

One major difference between the work of Abernathy and Utterback, on the one hand, and Klein, on the other, is that the former is more concentrated on particular firms. However, there is a surprising consistency in their overall results. For example, Figure II is taken from Abernathy's The Productivity Dilemma, and is entirely consistent with Figure I from the point of view of an individual firm. According to

FIGURE II

OPERATING TRENDS, FORD MOTOR COMPANY: NORTH AMERICAN OPERATIONS



Source: The Productivity Dilemma by William J. Abernathy
Baltimore, The Johns Hopkins University Press, 1978.

the Figure, labor productivity declined when new car models were introduced, and the curve became smooth only when relatively incremental changes were being made in product lines. Thus, when labor hours per 1000 pounds of car shot up in the late 1920s, it was because Ford was responding to the enclosed car.

For any firm responding to adversity at any time, the picture is much the same. However, while in the 1920s firms only had to pay a price in terms of productivity, now they must pay it in terms of both productivity and reliability: the price paid by VW when it was forced to go to the Rabbit, the price paid by American firms when they responded with cars of similar technological features, and the price that firms like Volvo and Toyota have yet to pay. It should be clear, therefore, that a good part of the explanation for the wide distributions shown on Figure I is that while some firms are milking a good thing, others are simultaneously taking actions that will force them to search for greener, but uncultivated, pastures. That is the very essence of technological progress.

More generally speaking, Abernathy and Utterback have described processes of "technological convergence" as a decline in both major product and process innovations as a technology matures. Initially, a new technology competes with an old one only in marginal applications. As more firms enter the industry, a widening variety of innovations are made, first in the product itself, and then in the production process. Finally, when both product and process innovations have leveled off, and the industry enters the incremental stage of development, the distribution is narrowed by the changes in character of firms as they become more concerned with exploiting already existing advances. In particular, when designed to produce large volumes of standardized products, firms become increasingly hierarchical: the requirements for a highly specialized labor force become greater as tasks are further subdivided, and management becomes preoccupied with marginal gains associated with vertical integration. A more detailed description of the differences between technological convergence and divergence is shown in Chart I.

However, Klein's behavioral dynamic economic analysis is more concerned with technological convergence as it is brought about by the drying up of hidden-foot feedback. From his point of view, changes in incentives are what is critically important, and what happens to the

CHART I

TECHNOLOGICAL CONVERGENCE VERSUS TECHNOLOGICAL DIVERGENCE

	Convergence	Divergence
Organizational Form	Hierarchical	Fluid and interactive
Flow of Communications	Up and down echelons	Highly unpredictable
Method of Control	Issuance of orders	Asking questions and internal competition
Relationship with Suppliers	As if part of the firm	Frequent divorces and new marriages
Character of Innovations advances	Highly predictable incremental advances	Highly unpredictable discontinuous
Tooling Strategy	Inflexible commitment to minimize tooling costs	Flexible to minimize cost of changes
Degree of Vertical Integration	High, to insure completely optimized design	Low, to insure rapid improvement
Overall Strategy Designed to Insure	Predictability in the small	Predictability in the large

technologies are merely interesting technical details. New firms entering an industry not only account for more than their share of discoveries, they also challenge established firms. However, as a technology matures, and entry costs increase, there is a sharp decline in entry and a consequent shift in incentives that results in a shift from dynamic to static efficiency. Thus, dynamic efficiency is concerned with making continuous advances in overcoming important technological limits and requires imaginative entrepreneurs; static efficiency involves incremental changes and occurs in firms that are pulled by a hidden hand, but not pushed by a hidden foot.

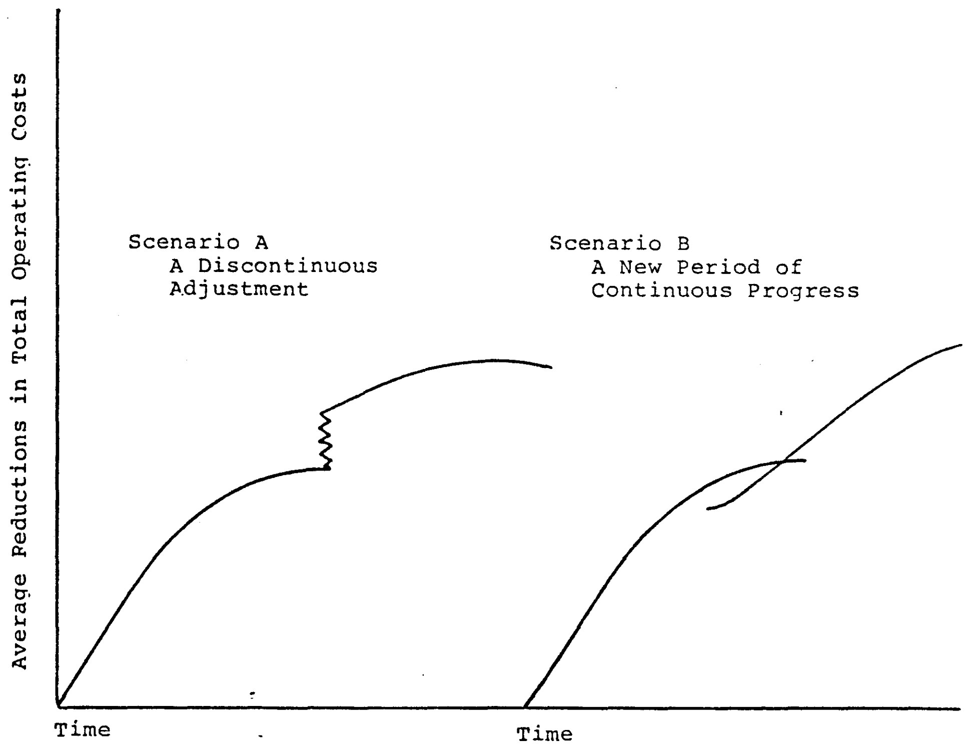
Two Scenarios for the Future Evolution of the Automobile Industry

As far as the future evolution of the automobile industry is concerned, two quite different paths are possible: the familiar S curve with a discontinuity or the generation of a new S curve (Figure III). The first would involve a more or less once-and-for-all adjustment in downsizing cars and providing them with lighter and more efficient engines. It would also involve buying engines and major components in countries such as Mexico or South Korea to overcome American and European firms' cost disadvantage. This first scenario is now taking place; it involves a hectic but relatively brief period of adjustment followed by the reemergence of the kind of static stability about which both production engineers and accountants love to dream.

The second scenario assumes that import restrictions on Japanese automobiles will be temporary (if longlasting import restrictions are adopted, the almost inevitable consequence will be scenario A) and involves approximately five percent annual reductions in total automobile ownership costs (measured in real terms)--including the original purchase price, depreciation, gasoline costs, maintenance costs, etc.--over the next twenty-five years. The assumptions behind this scenario are threefold: (1) While buyers will continue to want "more" or "less" luxurious cars, depending on their degree of affluence, they are becoming more conscious of the various attributes likely to minimize total ownership costs, including relatively good reliability as well as low gasoline mileage. They will thus engage in more comparison shopping, a

FIGURE III

TWO PATHS



behavior further encouraged by inflation and by the wider range of alternatives due to international competition; (2) While growth in total demand from the present depressed level will depend upon the performance of the worldwide industry in reducing total ownership costs, for the foreseeable future the automobile market will remain a buyer's market and competition will focus on ways to reduce ownership costs; and (3) Opportunities for further technological progress in the field of automobiles have not been exhausted. Although some automotive engineers believe that all major types of engines and fuels (the internal combustion engine, the diesel engine, the sterling engine, etc.) are now known, and that opportunities for changing the rules of the game within these well-known technologies are sharply limited, even the technological possibilities now in sight (plus the nontechnological measures needed to catch up to the Japanese in productivity) would permit substantial progress toward the goal of three to five percent annual reductions in operating costs. Moreover, five years from now, there will be new technological possibilities on the horizon about which relatively little is known today.

The Role of Rivalry in the Automobile Industry

Several reasons have been given to explain the present state of the U.S. automobile industry, including the impact of regulation (although foreign automobile firms are also regulated) and the failure of the government to decontrol the price of gas earlier (although the government did impose regulations with respect to fuel economy). It is true that in the period after 1975, the rise in gasoline prices abated and consumers shifted back to larger cars. However, long before the rise in the price of gasoline, competition in the industry mainly took the form of making cars longer and providing them with more powerful gas-guzzling engines.

It is certainly not true that the automobile industry never featured rivalry in terms of price and quality. During the period 1900 to 1925--the industry's finest hour--the quality of cars was improved, while at the same time the average price was reduced by a factor of seven![6] Quite clearly, there was a rapid rate of exponential progress with a wide distribution of outcomes, particularly in the lower price categories where a half-dozen firms were competing. When the Model T was first introduced, it was not the least expensive car on the market, but it provided the same dependability as Buick at a much lower cost. As a further consequence of rivalry at home, one-half of the cars sold in the world during the 1920s were either U.S. exports or cars made by U.S. subsidiaries abroad. Indeed, it can be predicted that when an industry displays the degree of risk-taking required for a wide disparity of outcomes, it will be exporting its products, and as rivalry declines, the industry will become increasingly vulnerable to import penetration.

However, while rivalry in terms of price stopped during the 1920s, it did not in terms of quality. As Abernathy has pointed out in detail, starting in the late 1920s, Chrysler led the industry in innovations and, as a consequence, rose to second place.[6] Moreover, while the GM masterplan did not allow internal competition during the 1920s, during the 1930s, when each division operated as its own profit-making center, rivalry broke out between Oldsmobile and Buick, with Olds pulling ahead of Buick in the early 1930s, and Buick again outdistancing Olds in the late 1930s. Indeed, the Great Depression can be regarded as the second finest hour of the U.S. automobile industry, for despite the enormous difference in profit rates, there was much more innovation during that period than during the period 1948 to 1965 (see The Productivity Dilemma).[7]

What happened after World War II? According to Raymond Vernon of the Harvard Business School, an inexorable product cycle operates: the U.S. starts out as an exporter of new products that are later produced by other industrial countries, after which the U.S. becomes an importer of the same product.[8] However, as was pointed out earlier, when U.S. firms are at war with each other, they export products to foreign countries, and when peace is declared they become increasingly vulnerable to import penetration. In addition, if the contestants are fairly evenly matched, we should not expect to observe a trade cycle. For example, chemical firms worldwide are simultaneously engaged in developing new chemical products and licensing chemical products developed by other firms. Why does it engage in this type of trade? From its very beginning, the industry featured a good deal of international rivalry which, while not nearly as continuous as one might like, resulted in chemical companies putting their first-rate chemists to work on new products, leaving chemical engineers the tasks associated with licensing.

On the other hand, the Vernon model makes good predictions in many other industries because when U.S. firms stop innovating they do indeed face a wage disadvantage. But why do they stop innovating? The basic reason, it would seem, is that, unlike the chemical industry, most other U.S. industries develop products purely for the domestic market. When rivalry dies out, they stop innovating.

But success breeds conservators, and the U.S. automobile industry's present predicament is a by-product of its splendid performance during the Great Depression. After World War II, most American automotive engineers believed that opportunities for further technological progress had been exhausted; therefore, if sales were to be kept at a respectable figure, other means would have to be found to entice the consumer. As Alfred Sloan made the point in My Years With General Motors (which was written during the 1950s):

> "In the course of time the product engineer raised the state of his art so high that he produced not only a superb creation but also a mature one, so far as the present type of gasoline powered car is concerned. Now he devotes much of his skill to solving the problems created by the stylist . . . Automobile design is not, of course, pure fashion, but it is not too much to say that the "laws" of the Paris dressmaker have come to be a factor in the automobile industry--and woe to the company which ignores them."[9]

If we are considering the period prior to the mid 1960s, before the number of foreign imports began to swell rapidly, there is no doubt that Sloan was absolutely correct in his assessment. Although the first high-styled Cadillacs built with long tail fins (to capture the image of the twin fuselage P-38 airplane) did not sell very well, when the idea did catch on, GM's sales zoomed. By contrast, Chrysler was not nearly as quick to learn the new game. It lost a very significant share of the market when it failed to keep up with GM and Ford in the adoption of the new look and then it ended up with the longest tail fins in the industry when GM and Ford were moving to cars with a more sporty look. On the other hand, Studebaker faired even worse: although the 1957 Studebaker was much like the foreign imports that were to swell the American market during the 1960s, to escape the tyranny of the majority it moved to Canada where it shortly went out of business.

Thus, what was operating was a tyranny of the majority that made the principle of commonality very profitable indeed. Long ago, de Tocqueville warned us that a tyranny of the majority would one day result in the undoing of democracy in America. And there can be no doubt that as far as the American automobile industry is concerned, a tyranny of the majority did dry up the generation of a diversity of ideas. Indeed, it is an open question whether the American culture, with its greater emphasis on standardization, does suppress a diversity of ideas in much the same way as de Tocqueville warned us (writing about 1835--even before the American concept of standardization was invented). Nevertheless, when firms create new fashions, they must accept the risk that styles eventually change: whether they be long automobiles or blue jeans.

By contrast, the role played by foreign imports during the 1960s was akin to the formation of new political parties. Consumers were provided with the opportunity of buying cars that would better suit their needs, as well as having the opportunity to change their tastes, which is precisely what they did.

It was not, however, the reliability factor that started the avalanche of foreign cars. Initially, California was the main market. In the 1920s, there were firms in Los Angeles that specialized in modifying cars (mainly for Hollywood and Beverly Hills actors and actresses) to provide them with the sleek appearance of a Russian wolfhound. The proprietor of one of these establishments (Harley J. Earl) was brought to Cadillac, where he founded the American school of automobile design. When, however, the same long sleek look finally became affordable by the common man, as was to be expected, the Beverly Hills and Hollywood consumers were the first to defect.

While automobile executives long believed that only eccentric Californians would buy foreign cars, during the 1960s foreign car ownership became much more widespread. Why? GM marketing people have disclosed that the main buyers of foreign cars are either well-educated or live in college communities. Indeed, it was found that foreign car ownership among GM executives living in Ann Arbor was far greater than those executives who chose to live in Detroit! As Abraham Lincoln once observed: "You can fool some of the people some of the time, but you cannot fool all of the people all of the time."

What effects did the absence of rivalry, except in stylist terms, have on the automobile industry?

1. <u>It resulted in extremely bureaucratic, overcentralized, and unadaptive organizations.</u>

As a result of GM's experience during the Great Depression, no doubt, Sloan was fully aware of the advantages of decentralization. As he made the point in a statement written after GM's experience during the 1930s:

> "From decentralization we get initiative, responsibility, development of personnel, decisions close to facts, flexibility--in short, all the qualities to adapt to new conditions."[10]

As stated, however, these advantages only occur when firms are at war. When, after World War II, peace was declared in the automobile industry, firms returned to a style of operation that was highly reminiscent of the 1920s. Given the fact that demand was rapidly expanding and that the advances made, while undoubtedly very exciting for the participants, were really not very significant, the movement toward a greater degree of centralized financial control was a highly logical development: the achievement of incremental gains in static efficiency requires a high degree of fine tuning, and centralization and coordination can supply the difference between making relatively nominal or relatively handsome profits. And, if its technological knowledge is assumed to be nearly perfect, the kind of internal competition that occurred during the 1930s is not only pointless but unproductive because all it can achieve is a bewildering array of options and differences in interior trim.

On the other hand, the primary drawback of highly centralized organizations is that, by being optimized to deal with a very small degree of uncertainty, they are ineffective when dealing with negative feedback should new circumstances arise--not because the engineers directly involved are slow to sense negative feedback, but because those who must deal with negative feedback have to operate under very formidable organizational constraints. For example, suppose that before the steersman on a ship can change its heading he either has to obtain the approval of five echelons of engineers, or persuade a committee of vice-presidents presided over by accountants whose main preoccupation is to avoid the costs involved in changing course. Such a ship, while admirably suited for sailing in calm waters, would be lucky to manage a single change of course in rough seas. When seas are rough, quick tactical decisions and not ponderous deliberations are required.

Very large differences in the complexity of automobile firms may also help explain why some have been more responsive to regulation than others. Research at the MIT Center for Policy Alternatives has documented this pattern. In emission control, for example, Toyota and Nissan (which appear to be large, centralized organizations) were the last to comply with Japanese regulation. Volvo and Saab, however, were the first to adopt an innovative three-way catalyst system--partially because they simply could not afford to make many incremental emission improvements and partially because they are relatively small companies.[11]

Another effect of a highly centralized environment is that it does not provide scope for the development of the individual. This does not necessarily mean the industry will fail to attract intelligent people. There are many bright engineers who love to work on tiny optimization problems. Rather, it means that creative engineers will be repelled by such an environment.

However, it should not be assumed that the real problem facing a number of automobile firms is finding the "right" balance between centralized financial controls and decentralized day-to-day operations. On May 21, 1981, The Wall Street Journal published an article entitled, "GM's Smith Wants A Leaner Firm With More Rivalry Among Its Divisions." According to the article, Smith would like the internal divisions of GM to compete just as they did during the 1930s, not by developing cars with trivial differences, but by having each division operate as its own profit center. However, while this seems to be a step in the right direction, we believe it is an open question whether such a change is sufficient.

The real question that we believe will require a great deal of further examination is just how much diversity of behavior there should be within an automobile firm. Certainly, from the standpoint of reliability, a good deal of coordination is required at all levels, not only between design and production people but also between the design people and those responsible for servicing the product. The often quoted example is the Japanese TV industry. And, as evidence that the achievement of high reliability does not involve adopting the Japanese culture, it may be pointed out that when the Japanese purchased American TV firms, they were able to improve reliability in some cases by a factor of 40![12]

To be more specific, the optimal organization for combining known technological ingredients is entirely different from that needed to search for new ingredients. For example, AT&T is structured so that it is Bell Telephone Laboratory's job to search for new technological ingredients, and Western Electric's job to combine them into highly reliable systems. Anyone familiar with these organizations will agree that they are entirely different. Western Electric is the epitome of the conservative engineering organization that adopts nothing new until it has been thoroughly tested--because the vacuum tube was so reliable, it was one of the last firms to adopt transistors. And there can be no doubt that if AT&T had only a Western Electric, improvements in U.S. telephones would have had to depend almost entirely on foreign technology.

By contrast, Bell Telephone Laboratories is a highly interactive organization--so interactive that BTL entrepreneurs will acknowledge that the authorship of new ideas is always in dispute. These interactions provide fresh ideas for the development of new systems; coordination, though, does not occur until experimental models have been built and tested. In fact, BTL has an unwritten law that detailed specifications for a new system cannot be promulgated until the system has been tested.

What might have been the result if AT&T had only a BTL and no Western Electric? Marvelous inventions would have been made, but reliability would have been so poor that if it had wanted to survive, BTL would have had to transform itself into a Western Electric. What would have happened had AT&T sought a happy medium between these extremes? It seems reasonable to assume that the telephone system would embody neither the reliability nor the technological improvements it has demonstrated to date.

In short, there is no happy medium between static and dynamic efficiency. Entirely different organizations are required to achieve the advantages of each type of efficiency. Nevertheless, there is a crucial question involved: how can ideas be transferred from an R&D facility to a production organization? Before World War II, this was no problem at AT&T: competitive pressures were so lacking that there rarely was any urgency to move quickly from experimental models to production. However, since World War II, AT&T has had to deal with a series of threats to its monopolistic position. It would be interesting to learn what organizational changes have been made to permit it to act rapidly in the face of this negative feedback.

Even more relevant would be information on how Honda spans the bridge between R&D and production activities, or how VW goes about transferring ideas from its experimental cars to its production automobiles. If our information is correct, Honda's R&D activities are conducted in a wholly owned subsidiary, the Bell Labs of Honda, so to speak. What are the problems Honda has encountered in transferring projects--such as the stratified charge engine--to production? In particular, what means are employed to guard against poor reliability?

To conclude this discussion, while predictability in the small can be likened to a Western Electric without a Bell Laboratory, predictability in the large involves both. So the more basic question raised above is: how far might automobile firms go to increase their predictability in the large?

2. The absence of rivalry produces a method of managerial compensation that stifles the initiative required for predictability in the large.

Firms that must deal with significant amounts of hidden-foot feedback in their external environments must adopt incentives that will encourage a good deal of internal risk-taking if they are to survive. In such firms, big bonuses for creative accomplishments are awarded shortly after they are made. Moreover, managers who never make a mistake are not promoted. There are, of course, major differences between firms in the degree to which they emphasize pecuniary and nonpecuniary rewards. For example, if our information is correct, in Japan creative people are typically rewarded by being given interesting jobs. And in the United States, Bell Telephone Laboratories rewards researchers much like Japanese firms are said to reward them.

On the other hand, until the swelling of foreign imports during the 1960s, the automobile industry could have been fairly described as one in which there was a very delicate balance of power. Ford and Chrysler did not dare start a war they did not have the resources to finish. For fear of an antitrust suit, General Motors did not dare drive either Chrysler or Ford out of business. Consequently, price competition was virtually nonexistent. While it has been traditional for Ford and Chrysler to announce their prices before GM, it also has been traditional for GM to have a last word on this subject; within a few weeks after prices are announced at GM, it can be predicted that Ford and Chyrsler will bring their prices into consonance with GM's,[13] a pattern that has begun to change only during the past few months. Moreover, the close resemblance between the products of the auto firms is not entirely coincidental. Helicopters are employed to spy on each other's test facilities--and in a number of cases Ford has engaged in expensive last minute changes to make its automobiles look less different from those of GM. Indeed, when Klein visited Ford in 1965, about a dozen engineers seemed to intimate that, while they could undertake R&D projects to prevent GM from obtaining a lead (for example, with the Wankel engine), they are rarely allowed to undertake a project with the enthusiasm required to obtain a lead. Or, if allowed to go ahead with a promising new development, it must be able to compete directly with existing technology. Thus, the Ford PROCO engine technology was commanded to result in the same fuel consumption as GM's diesels, and it had to be available in 6- and 8-cylinder versions.

It should not be assumed, however, that overconstraining R&D projects is the only problem in the U.S. automobile industry. While one company may be imposing such constraints, another may have its research people engaged in writing the same kinds of articles they would write if they had remained in the universities. Between these extremes is a happy medium: exploratory development projects that are conducted in the spirit of scientific research but directed to practical ends. According to scientists, science is "what works." And what R&D people in every industry should be doing is using hints from previous experiments to generate new ideas and then experimenting to discover "what works."

Considering the fact that the balance of power in the automobile industry was quite as delicate as that which kept the peace in Europe during the nineteenth century, it is not altogether surprising that a system of internal incentives evolved which caused managers to be wary of risk-taking: a fact of life that in itself will result in technological convergence. In particular, something like fifty percent of managerial compensation is given as bonuses during prosperous years--bonuses which cannot be withdrawn until retirement. Hence, as engineers from the industry have often pointed out, the longer one stays with the company, the greater will be the penalties for leaving. Consequently, the longer one stays, the greater is the incentive for cautious behavior. Moreover, it is also pointed out that when engineers take risks which do not pay off--as, for example, the Ford program to develop a turbine engine for trucks--they are usually fired. Are such incentives to be regarded as "rational" or "irrational?" If you assume that the name of the game is to keep the peace, they are eminently rational. But quite the opposite is true when an industry must deal with a good deal of rivalry.

If an industry features a negligible degree of rivalry and little internal risk-taking, then, when its environment becomes more uncertain, it can expect to pay a penalty both in terms of relatively poor productivity performance and a loss of competitiveness. As far as the American automobile industry is concerned, the rate of technological advance was certainly impressive, especially when compared with manufacturing as a whole. Moreover, the introduction of new technology such as transfer technology played a significant role. Nevertheless, it is an open question whether U.S. firms were as quick to adopt best practices as firms like Volvo, who have engaged in international competition for a longer period. And if we are considering the period prior to 1960 or 1965, when foreign imports began to make a real dent in the American market, how much of productivity gain is to be explained by going towards a mix of larger cars: cars whose prices increased more than their costs. This question too will require more attention than it has received to date.

What seems to be quite clear is that if we compare American compacts with Japanese compacts, it is apparent that the Japanese do have a considerable advantage in productivity and, even if we do not take differences in wage rates into account, in competitiveness. Abernathy's recent research indicates that productivity and wage advantages each amount to approximately $750, which gives a Japanese compact a $1500 cost advantage.[14]

How to explain the Japanese productivity advantage? It is true that, in comparison to the United States, the Japanese have smaller manufacturing inventories when cars are in the production pipeline, they employ an entirely different method of quality control, they are ahead in the use of robots, and they enjoy fewer hours lost to absenteeism, etc., etc. But it is more important to examine those features of the Japanese automobile industry that enabled it to generate this competitive advantage in the first place. It certainly cannot be argued that Japanese automobile manufacturers were blessed with greater opportunities for cost savings because they were using larger plants. For example, the largest Toyota plant employs 6,400 workers, and is smaller in output terms than are either GM plants in the United States or VW plants in Europe.

It is our hypothesis that the Japanese have a competitive advantage because their post-World War II industry was characterized by a greater degree of internal rivalry--much as characterized the U.S. auto industry during an earlier period--and the competitiveness of the Japanese industry owes a great deal to the fact that in the past, anyway, Japanese consumers have been better comparison shoppers than their American counterparts. It is true that the Japanese industry was also protected from foreign competition, but as long as an industry generates a good deal of internal hidden-foot feedback and does not have large enough plants to engage in international competition, protection need not be the vice it is in an industry faced with a critical shortage of hidden-foot feedback.

How might it be determined that the Japanese automobile industry is or is not characterized by a higher degree of rivalry than the United States' and, if so, that such rivalry played a key role in generating productivity gains? First, we will need a measure of the "tax" imposed by rivalry: the impact on other firms' sales of particular cars, market shares, and profits when particular firms were successful in introducing lower cost or better quality cars. Second, for cars of more or less the same weight, we will need a measure showing the distribution of more and less successful cars with respect to the total ownership costs (i.e., the revealed response to the "tax"). Third, we will need historical information to determine the rate of exponential progress.

In addition, we also would like to know more about the factors that have made Japanese automobile firms as adaptable as they apparently are. According to Klein's model, both the imitation of a series of successful innovations and actually bringing about such innovations require highly adaptive organizations. Conversely, making marginal advances requires firms that are highly specialized and routinized. Consequently, a bifurcation appears in the model at which point either fairly significant advances or imitation become preferable alternatives.[15] The question is where we find Japanese firms poised: at either end of the distribution, but not in the middle? And how might such a relationship--if it exists--contribute to the overall stability of the industry? Finally, we would like to know what role foreign markets play in the calculations of Japanese automobile executives.

To provide definitive answers to questions like these, it will be necessary to know how this productivity achievement came about. These answers, in turn, can then be applied to the American automobile industry. There are many who say the Japanese culture made the difference. But we are skeptical. Another inquiry Klein is undertaking--how productivity in Sony's San Diego plant compares with Sony's performance in Japan--may also help shed some light on this question.

3. <u>What is the effect of the lack of rivalry upon wage rates?</u>

On the basis that wages in the U.S. automobile industry are 45 percent higher than for manufacturing as a whole, it has often been argued that wages in the industry are excessively high. However, it also can be observed that during the period 1957 to 1975, output per employee hour in the U.S. automobile industry increased by as much as did hourly earnings.

On the other hand, what may have made the automobile industry different from many, but certainly not all, manufacturing industries is the extent to which its productivity gains were the result of a shift in output toward large, powerful cars with a relatively high mark-up. As was indicated earlier, understanding better how changes in the composition of output are reflected in productivity gains is something that will require a great deal of further work.

Table I shows that, despite the threat of Japanese penetration of their markets, wage rates in nearly all of the Western countries have gone up quite rapidly. How is this to be explained? There are many conservative economists who blame it all on the labor unions. But, as was already noted, it also must be observed that high wage rates plus a variety of restrictive union practices go hand in hand with the absence of rivalry in price or quality. Whatever the explanation for this discrepancy, one thing is clear: if economies are to remain viable, international wage differences can be tolerated only to the extent that they are supported by productivity differences. For many years, people complained that the gap between the more and less affluent countries was increasing. But now, when lower wage rates in Japan provides them with a competitive advantage, we complain--and when lower wage rates in Korea provides them with an advantage, the Japanese complain. The complainers should be simply told that if they want to maintain artificially high wages, unemployment is an inevitable consequence.

TABLE I

INDICES OF HOURLY COMPENSATION OF PRODUCTION WORKERS IN THE MOTOR VEHICLE AND EQUIPMENT INDUSTRIES

(U.S. = 100%)

COUNTRY	1975	1976	1977	1978	1979
France	54	53	53	59	65
Germany	80	78	83	93	102
Italy	53	48	48	53	58
Japan	37	39	42	53	50
Sweden	78	81	78	77	84
United Kingdom	41	36	34	38	46

Source: U.S. Department of Labor, Bureau of Labor Statistics, Office of Productivity and Technology.

TWO PUBLIC ISSUES

When to Protect and Not to Protect

The first question that must be resolved is under what circumstances it is desirable for a government to protect an industry. The answer is quite clear: when an industry is at a competitive disadvantage because its firms are not yet large enough to enjoy the benefits of scale economies achieved in other countries, but they feature a good deal of internal rivalry. Although protection was continued longer than necessary, this was the position of the Japanese automobile industry after World War II, and within a very few years Japan became a major exporter of automobiles. It was also the position of the U.S. steel industry during the 1880s, and by 1900 American steel making firms were selling steel to Scottish shipbuilding firms. Finally, this was the position of the U.S. auto industry in the 1900s when there was a 45 percent tariff; at the same time, rivalry was at a peak.

On the other hand, to better understand the effect of protection when rivalry is dying out of an industry, consider the British-Scottish steel industry. While, as of 1900, this industry was becoming increasingly vulnerable to competition from U.S. and German steel firms, rivalry was still somewhat alive due to the entry of new firms such as Colville. Moreover, because foreign competition resulted in unemployment in the industry, a rather novel method of wage determination was agreed upon: when, in the absence of competitive pressures, market forces permitted steel prices to rise, wage rates increased in proportion to the rise in prices, and when it was necessary for British and Scottish producers to reduce steel prices, wage rates were proportionately reduced. Until the early 1930s, wage reductions under this formula occurred quite as frequently as wage increases.

However, while this method of wage determination helped protect the ability of the British and Scottish steel industries to compete with German and American steel firms in terms of cost, it did so by shifting the burden for dealing with unpredictability from management to the workers. Consequently, rivalry with German and American steel firms did not have nearly the effect it might have had in stimulating productivity gains. The wage formula was the first step toward a protected industry because it created, in effect, a zero-sum game.

The second step occurred in the early 1930s, when the British Labor Government slapped a thirty percent tariff on steel imports and required that the industry rationalize itself by combining small firms as a condition for the continuance of the tariff. No doubt, this unification made it easier for the labor unions to push for uniformly high wages, but at the same time, it deterred rivalry in the industry. Consequently, these actions shifted the burden for dealing with unpredictability to British society as a whole which, in turn, paid a high price in terms of contributing to Britain's lower standard of living.

The final step occurred after World War II when the industries were nationalized. Why were they nationalized? It is often said that an industry that had played such an impressive role in Britain's economic history simply would not be allowed to disintegrate. But an even more important factor may have been at work: the Protestant Ethic, as it is typically interpreted in most Western countries, requires that workers be kept at their jobs until the day they retire--no matter what this worship of tradition costs society at large.

Thus, protecting an industry that already possesses a good amount of competition need not necessarily result in any lasting harm to society as a whole. But when an industry is characterized by little or no rivalry, protection merely shifts the onus for dealing with unpredictability to society at large by ratifying those practices that made protection necessary in the first place (e.g., a highly inflexible method of planning, overly centralized organizations, little or no pressure to bring about productivity gains, and a lack of constraints on wage increases). In addition, although protection is intended to cure chronic unemployment problems, protected industries usually have the most serious chronic unemployment problems.

Moreover, once the game in a protected industry is seen as a zero-sum game in which the size of the pie is strictly fixed, all public policy issues are seen as distributional issues and conflict between labor and management becomes greatly heightened.

This discussion leaves open the question of whether a temporary restriction of imports, such as that recently announced, will have a detrimental effect on the rate of progress. It may be granted that a six or seven percent reduction in Japanese imports for a period not to exceed two years probably would not do serious injustice to the principle of steady competitive pressure. However, it can be predicted that a longer period of protection would do nothing more than transfer the burden of dealing with unpredictability to the consumer.

What should be done? Those who favor protection point to the large amount of unemployment in the automobile industry that the United States is likely to have without it. Indeed, it cannot be denied that a return to the earlier growth paths with respect to worldwide demand is quite unlikely, and that many countries consequently will face problems of chronic unemployment in their automobile industries. However, as will be pointed out in the next section, the humanitarian issue and that of producing economical automobiles are completely separate problems. There are not many people who would propose to deal with the problems of the unemployed by having some workers dig holes in the ground and others fill them up again. Operating an industry with a disguised unemployment of something like fifteen percent results in precisely the same thing. If the restrictions on Japanese imports are made permanent, we will have a program of disguised unemployment.

It is true that, as already indicated, temporary import restrictions need not have the effect just predicted. But it is also true that, while temporary import restrictions will ease the financial problems of American automobile firms during the transition, they will not preclude the possibility of one or more American firms failing afterwards. Indeed, inasmuch as import restrictions provide an additional incentive for foreign firms to become established in the United States, protection may actually hasten the demise of unadaptive U.S. firms.

It is generally believed that if competition is restricted, the effect is to make for less unemployment. However, quite the opposite is true: competition stimulates employment. As long as competition results in lower operating costs--by providing the consumer with more and more value for his or her dollar--employment opportunities will be increased. Physical assets will not be left abandoned or unused anymore than in the television industry when American firms were challenged by Japanese TV firms.

Another possibility is the entry of petroleum companies into the automobile business, for these firms have incentives with respect to energy conservation that may be in greater accord with the public interest. When automobiles were first developed and oil supplies were ample, the petroleum companies played a subordinate role by working according to the requirements of the automobile industry. But the time has come to ask if the relationship should now be reversed: the incentives of petroleum companies may be in better accord with the public interest. For example, Texaco already has entered the automobile business by developing a stratified charge engine for truck use.

What is clear is that for continued progress, the worldwide automobile industry will need to be composed of at least as many firms as currently exist. As was indicated in the first section, according to a statistical model based upon a Poisson distribution, ten independent profit-making centers in the worldwide automobile industry engaged in making quite independent experiments are none too many--and this estimate makes no allowance for redundancy. Even if we assume that the competition does not occur entirely in the form of manufacturing complete automobiles, but, rather, of firms working on novel engines, new fuels, new batteries, etc., we are still talking about an industry in which worldwide rivalry will be required. Even in the field of semiconductors, where the cost of experimentation is lower, exponential progress has been maintained only by the Japanese getting into the game.

In short, while static economists do not like protection because it prevents the static law of comparative advantage from working, dynamic economists do not like it because in their view rivalry is the driving force in generating better or less expensive alternatives.

Separating Humanitarian And Dynamic Efficiency Issues

The second important policy issue concerns dealing with problems of serious chronic unemployment that arise not because of competition but because of a shortage of effective demand. One conceivable way to make up for the lack of worldwide demand of automobiles would simply be to provide very generous unemployment benefits. Such a measure would completely separate the humanitarian issue from the issue of producing attractively priced cars.

On the other hand, it also must be acknowledged that overly generous unemployment benefits to workers--say, the guarantee of jobs at present rates of pay--could destroy their work incentives. There is a big difference, though, between this safety net for unemployed workers and that which unemployed workers are currently provided.

The issue, therefore, is what benefits might be provided to avoid either one of these extremes. Two kinds of research are recommended in order to become better informed in this regard. First, we propose looking into the Japanese experience or, for that matter, into that of any country which might provide relevant information on sensible ways to deal with problems of the unemployed. In Japan, for example, interpretation of the Protestant Ethic does not require that workers in stagnating industries be kept on their present jobs until they retire: Japan is dealing with unemployment problems in her shipbuilding industry by providing jobs, but not necessarily in that industry.

Second, we propose to examine cost differences between offering rather generous unemployment benefits plus retraining expenses, on the one hand, and observing the current form of the Protestant Ethic, on the other, by keeping unadaptive industries alive. (Currently, engineers from the Japanese shipbuilding industry are being retrained with labor union funds at MIT!) It is our hypothesis that the second alternative is so costly compared with the first that no country can afford it.

DYNAMIC EFFICIENCY

Dynamic efficiency is the efficiency involved when dealing with adversity. Suppose, for example, that two automobile firms are suffering a similar loss in sales, but, whereas one responds promptly and effectively, the other responds late and ineffectively. It may turn out that the relatively poor response of the second results from a lack of financial resources. But, if not, the first can be said to demonstrate a higher degree of dynamic efficiency. Thus, during the Great Depression, both Oldsmobile and Buick displayed a high degree of dyanamic efficiency, though not nearly as high as surviving automobile firms displayed in the 1900s. VW also evidenced a high degree of dynamic efficiency when going from the Beetle to the Rabbit cars. On the other hand, the long time taken to restore Chrevrolet's market position during the 1960s does not suggest an especially high degree of dynamic efficiency.

This is not to say that the effectiveness and timeliness of responses are always positively correlated. One can imagine firms in which ponderous deliberation is followed by swift action. However, while dynamic efficiency as just described can be determined only after the event, the question is--what limits a firm's ability to engage in a dynamic response?

The Importance of Options in Providing Flexibility

Dynamic efficiency is constrained by a lack of diversity of technological options or by a lack of flexibility to introduce new options. In turn, both diversity and flexibility are constrained by vertical integration which, while an asset from the point of view of static efficiency, is a liability from the point of view of dynamic efficiency.

The essential objective of dynamic efficiency is to encourage the generation of a diversity of ideas required for exponential progress. This diversity will be maximized when the various activities of firms are conducted as independent profit centers. For example, in a dynamically efficient automobile firm, the engine and assembly activities would be conducted as completely separate operations. Therefore, if a Ford or GM engine profit-making center could not sell a new engine internally, it should be free to sell its engines to another company.

On the other hand, the automobile assembly people also need to be free to choose. If they can make a better product by optimizing their auto body to someone else's engine, why not? For example, Mr. Olds might have preferred to enter the diesel business with a 6-cylinder diesel and a smaller car. But, by having to use the GM intermediate body required for reasons of commonality and an 8-cylinder diesel engine, his choices were more constrained than they need have been. In short, vertical integration in which the new must compete directly with the old imposes very serious constraints for developing new options. And we are delighted to hear that GM is moving towards giving the division heads a freer hand.

It is true that with American automobile firms buying both internal combustion engines and diesels abroad, the industry is moving away from vertical integration. But we believe that public action can be directed toward accelerating this process. As an illustration, consider the action of the U.S. government during the 1920s (when Calvin Coolidge was President) to expedite the advent of the air-cooled airplane engine. It first set up the Lawrance Aero-Engine Corporation, a private company, to build experimental engines--and, when this effort proved to be successful, Pratt & Whitney, a New England machine tool firm, was persuaded to go into the airplane engine business. Although there are people who claim that only in Japan can such things be done, the fact remains that it was the United States that pioneered such operations. However, we are not arguing for <u>public</u> R&D organizations; their role is to provide a form of recreation for engineers who enjoy inventing clever devices for themselves.

In short, our model of a future world automobile industry engaged in exponential progress is one in which dozens of small firms--battery companies, companies engaged in developing novel engines, companies engaged in making hydrogen fuel from water, companies engaged in making hybrid electric and gasoline powered cars, etc.--will be proving to the major firms in the industry that, their microscopic calculations notwithstanding, new options can be introduced in such a way as to reduce the costs of experimentation and entry.

Moreover, as already has been accomplished in Germany, first-rate university engineering departments should be brought into the act. It should be noted that doing this and starting small firms are highly complementary activities, because university professors and small firms work well together; indeed, it is no exaggeration to say that this was a key factor in the United States becoming the technological leader of the world. Conversely, when university departments continue to work for firms that have become unprogressive, they tend to take on the same coloration.

Will established firms buy technology invented in small firms? Of course they will. When the backsides of management are kept to the fire, they become very eager customers of new ideas. To be sure, they might prefer a world of zero-competitive pressure in which it is much easier to say "no." But, if one pressed firm cannot afford to say "no," another less pressed cannot afford not to say "maybe." In a dynamic industry, this is how firms make rapid and effective responses to negative feedback.

Nevertheless, it must be acknowledged that there may be a problem in getting sponsoring organizations to behave in the required manner: they usually prefer to make risk-capital grants to larger firms because, if the project in question turns out to be a failure, they cannot be blamed. In other words, they prefer to subsidize well-established firms rather than bring about technological progress. Moreover, these people have a tendency to develop pet technological projects, and to make working on them a lifetime undertaking. Thus, it is important to get people into the sponsorship of private R&D who do not want to make a lifetime career in this activity, and conduct the activity mainly with ad hoc organizations.

In sum, the ability of an industry to respond quickly and effectively in the face of negative feedback depends not only on the options internally available, but also upon the options externally available. However, there is no market mechanism that will automatically generate the needed options. The more basic problem is that, unlike Japan, the United States simply does not have the financial institutions required to advance risk capital. As Harry Truman once make the point: "Banks loan money only to people who do not need it." The same may be true in other countries as well. In the past, private sources have helped to insure that venture capital was not lacking. But it is questionable whether under today's conditions such capital would be available for high risk ventures.

If, as seems likely, a shortage of risk capital turns out to be a major limiting factor, there are further questions about appropriate mechanisms to remedy this shortage. One possibility used to great advantage in the United States during World War II was a "fixed-price grant." Suppose that a company, such as Westinghouse, has good ideas for developing a new kind of radar. It would be given a fixed sum of money, say $500,000, to develop an experimental model. If the model did not work as advertised that would be the end of the matter. Of course, operating in such a manner would require ad hoc organizations composed of people who had the required technical expertise. But the United States should not have to become involved in another World War to create such organizations again.

Government loan guarantees might also be employed to encourage entrepreneurial banks (such as Citibank). If the government is really concerned about promoting the vitality of the U.S. automobile industry, why not guarantee loans to small firms? Although more than half may fail, a few may turn out to be outstandingly successful. Inasmuch as risk-taking does provide a benefit to society as a whole, it can be argued that society should be willing to pay for part of the cost of unsuccessful ventures, particularly when the difference between success and failure is often a matter of luck.

These matters will require further study. But there is one point that does seem to be clear: whenever governments advance risk capital to new firms, they should be made to bear approximately 50% of the risk.

Subcontracting

Perhaps the most important way of providing more options in the automobile industry is through the relationships between major firms and their suppliers. But it must be emphasized at the outset that subcontracting does not automatically generate options. In particular, when a subcontractor and a firm work together as almost a single entity, this may be worse than vertical integration, because it involves a relationship in which neither party is engaged in any new thinking. Conversely, from the viewpoint of dynamic efficiency, the best subcontracting relationship is one in which divorces occur quite regularly, either because the subcontractor finds another major firm more willing to accept new ideas or the major firm finds that the subcontractor has stopped generating new ideas.

Subcontractors also reduce the cost of entry. While it is probably naive to think that, given the major barriers to entry presented by the capital costs of production and distribution, any (or many) new major firms will enter the automobile industry as rivals, entry via new engine, battery or other such firms is by no means out of the question.

Inasmuch as suppliers provide components and materials for manufacturers as well as machinery and control for the production process, they can substantially affect the firm's character and flexibility. If the firm has a strong, dependable, and flexible set of suppliers, it will be freer to choose among alternative product designs or approaches, or to broaden or narrow its product with greater ease than otherwise would be possible.

Suppliers have been known to be strong sources of innovation in the auto industry. Lawrence White, in his book on the automobile industry, contends that the major innovations--especially those affecting performance of the automobile over the last 30 years--have mainly been initiated by suppliers who have played a strong role diffusing such innovations across the industry and increasing competitive forces among the major manufacturers.[16] And, more recently, suppliers have played a major role in developing emissions technology.

Abernathy and Utterback's research on innovation also shows that, as an industry shifts its focus to competition based on product cost and quality, suppliers play an increasingly strong role in introducing major changes in both products and production processes. Thus, suppliers may enhance the flexibility of manufacturing firms, not only by reducing their need for capital investment and vertical integration, but also by contributing to creative sources of redefinition of elements of the product as a whole.

Supplier relationships may hamper innovation if a firm becomes dependent on captive suppliers--with emphasis on incremental and cost reducing innovations--by forcing such suppliers to accept low rates of profits with large fluctuations in demand. Conversely, if the firm cultivates more diverse suppliers in terms of the market they serve or in the range of the products they offer, or if these suppliers support high profits from supplying automobile firms which they can reinvest in research, or if the suppliers are specialized by type of technology rather than by the diversity of markets they serve, one might expect them to play a stronger creative role. The importance of flexibility in relationships with suppliers then lies in the new ideas and technologies which new suppliers and creative established suppliers provide. Unstable relationships with suppliers aimed at lower prices for standard technologies would conversely tend to frustrate innovation, as would a policy by manufacturers of shifting most risk to suppliers but quickly producing any resulting successful developments themselves. One would expect relationships in which manufacturers pool risks with suppliers, and in which suppliers gain rewards from their successful developments for a reasonable time, to be more conducive to rapid rates of innovation.

Supplier relationships may also help to explain some of the apparent cultural differences in the automobile industry between firms based in Europe, the United States, and Japan. For example, it has been claimed that, while the degree of vertical integration in Japan is quite low, suppliers are, in effect, integrated into each firm's manufacturing process. Such supplier relationships would enable a firm to lay off fewer people during downturns, but would not be so helpful in promoting creativity. German and European suppliers, in general, have a reputation for a high degree of independent innovation and advancement of automobile industry technology, and, as such, would be a major asset to meet changing conditions of demand and technology.

One might contend that in the past, the United States has had the strongest infrastructure of suppliers and diverse technologies, although some concern has been expressed about the strength of supplier firms in the area of production technology and automation. Indeed, the strengths of U.S. suppliers in materials and electronics may turn out to be the key To the competitive vitality of U.S. industry in future years as more major changes are demanded of automobile manufacturers.

Supplier relationships in terms of what is sold to whom, and which suppliers are drawn on in periods of evolutionary and more rapid change, should be measurable, subject to study and crosscultural analysis, without intractable problems of definition and meaning of data. While it is very difficult to measure the importance of individual innovations, we can learn about not only the degree of subcontracting in various countries, but also: (1) the character of the subcontracting relationships; and (2) the various constraints involved in shifting to a mix of a more R&D intensive method of subcontracting.

Taking Risks in Small Packages

Sometimes, firms bet fortunes that particular technological accomplishments will turn out to be the dominant approaches for many years. And they may be lucky or unlucky. If lucky, people will exclaim, "What brilliant planning!" But, if they are unlucky, an almost inevitable result will be an abhorrence for risk-taking that may have disastrous consequences in a later time period.

How, then, to avoid becoming involved in such a predicament? All firms must devote some significant proportion of their R&D budgets to seemingly "safe" bets, even though they may not turn out to be so safe. If a firm is genuinely interested in securing its longer-run survival, it is absolutely essential to put some significant proportion of its R&D resources into relatively high-risk projects. Moreover, it is imperative not to directly compare high- and low-risk projects.

More often than not, however, the risks associated with developing new cars cannot be minimized by building experimental models and testing them on the so-called proving grounds. Even if the automobile looks great during first tests, some new models encounter such serious reliability problems when introduced that even after these are corrected it can take several years to win back consumer interest. Thus, although a few old-fashioned engineers still believe that you test an automobile to prove the design, the fact is that until tested in the marketplace the design is never proven! The question, thus, is how to go about introducing new models in such a way that permits the incorporation of significant advances and also minimizes the risks of costly retrofit programs.

There are many who believe there is only one "right" way to tool (i.e., tooling in a manner to minimize high volume production costs) and, regardless of the risks involved, the only correct way to tool is to "tool right" from the beginning. However, a single example--the experience of several aircraft firms in tooling for noncommercial airplanes after World War II--should indicate that, generally speaking, managing for uncertainty and the appropriate kind of tooling are inseparable issues.

During the war, when single firms produced hundreds of airplanes of the same design, the production people learned to tool much like firms in the automobile industry. In fact, the production people were so proud of their achievements that they resolved to never again tool in the "backward" way they had before World War II. But the engineers engaged in developing new planes were not nearly so happy. They found that when modifications had to be made in tooling, the cost of discarded tools was often equal to a very significant fraction of the cost of developing a new plane. Furthermore, the time required to make the tooling changes was so great that, in several cases, the firms lost the competitive advantage they might have enjoyed had it been possible to deliver a reliable airplane earlier.

So what to do? Had it been the early 1930s, they might have produced prototypes with soft tooling and then gone to hard tooling. But, considering the tolerances required to build a reliable long-lasting airplane, that was out of the question. Therefore, after a good deal of turmoil (when many tooling people were told that if they persisted in their old ways they should go to work for automobile companies), they finally worked out the concept of flexible and expandable tooling: initially only one assembly fixture would be used per wing and, later, when the bugs had been worked out, the tooling would be expanded to four fixtures.

Tooling in this manner did cost something above that involved in going directly to relatively high volume tooling. However, when one compares the additional cost of changing four assembly fixtures instead of one, and the benefits of being able to deliver planes whose performance was guaranteed by the aircraft companies (with sharp penalties for noncompliance), the additional costs were of negligible importance.

This is not to say, however, that once this lesson was learned it was learned for all time to come. For example, Douglas was so worried that Boeing would obtain a marked advantage with its 707 jetliner that, when developing the DC-8, they decided to take the risk of going directly to full-fledged production tooling. However, Donald Douglas, Sr. later remarked that this was one of the most expensive decisions he had ever made in his life: while, on the basis of a prototype jet airplane it had quickly developed, Boeing was able to obtain orders for both commercial airplanes and a military tanker airplane, the Douglas Company was involved instead in a hectic effort to make changes in airplanes and tooling.

Another example concerns the use of computerized machine tools. The general way these tools are used is to eliminate the need for the general purpose and highly versatile machinist. But, there are German machine-tool companies that do not operate in this way: they have sent their machinists to American schools to learn the computer programming. Then, upon returning to Germany, the machinists act as a flexible link between the R&D people and the production people. Thus, while in the former case, computerized machine tools are used to routinize the production process, thereby making it more difficult to bring about changes in products or production processes, in the latter case they are used to facilitate change.

By citing these examples, our purpose is not to suggest that tooling concepts employed in other industries are directly transferable to the automobile industry. What we wonder is whether, with respect to a question as important as this, there would not be some advantage to the industry as a whole for working out some mechanism for acquiring better information on each other's experiences? For example, in the case of commercial airplane tooling after World War II, there was a great deal of information exchange between firms because they had a common problem. This information exchange resulted in a change in the general direction of tooling. Could not this method of operation be transferable to the worldwide automobile industry where the achievement of a greater degree of dynamic efficiency is certainly a common problem?

AN INTEGRATED RESEARCH PROGRAM TO INVESTIGATE FURTHER THE OBSTACLES TO DYNAMIC EFFICIENCY

In this last section, we will summarize the preceding discussion and present a proposal for an integrated research project that focuses heavily on the more specific research suggested in earlier portions of this memorandum.

Dealing with Strong and Irreversible Uncertainties

To clarify what we mean by "dynamic efficiency," we must to distinguish between two kinds of uncertainties: weak and reversible, and strong and potentially irreversible. Weak and reversible uncertainties affect the day-to-day tactical operations of a firm. They are typically dealt with by the establishment of a routine procedure for making minor shifts in production. For example, it is obviously easier to predict the day-to-day fluctuations in the total demand for compact cars than it is the fluctuations in the demand for individual makes. Consequently, one important advantage of producing several compact cars on a single production line is that it is easier to reschedule production when demand for an X-model Olds turns out to be greater than was expected and of an X-model Pontiac, smaller. In short, such a response can be described as completely preplanned.

In contrast, strong and potentially irreversible uncertainties are those that can affect the future of an entire product line--e.g., when the open car was made obsolete by the enclosed car, or the present X-model designs are made obsolete by a series of equally promising new features. The uncertainties in question are described as "strong" because there is no way of predicting on a probabilistic basis when particular discoveries will be made. They are potentially irreversible, because failure to act on the basis of such uncertainties can impose serious penalties. Nevertheless, while it is not possible to make probabilistic predictions when uncertanties are strong, in general, the stronger the uncertainties, the greater number of ways an industry can evolve. Thus, while strong uncertainties provide an industry with more risks, they also provide it with more opportunities.

How do firms deal with strong uncertainties? Because it is not possible to take out insurance (unless the government provides it), firms must somehow respond quickly and effectively in the face of negative feedback. As was suggested, the problem has several dimensions:

1. Going to a lower degree of vertical integration, because this permits the generation of a wider diversity of ideas.

2. Substantially broadening the boundaries of the industry via subcontracting, because this decreases entry costs and increases the number of ways an industry can evolve.

3. Finding more flexible methods of tooling, because this permits taking risks in smaller packages.

Needed Research

We have listed a number of factors that can limit the ability of firms to respond promptly and effectively to negative feedback. Also, we have indicated why there is a genuine need, from the standpoint of society as a whole, to keep the worldwide automobile industry at war.

However, if people from the worldwide automobile industry want to survive, and at the same time have fun, it would seem that they would have an obvious interest in learning as much as possible from each other about the requirements for adaptability and dynamic efficiency. Certainly, different firms in the industry have displayed varying degrees of adaptability. And, while one or another of the above mentioned factors no doubt have played a role, we assume that there would be general interest in acquiring more knowledge with respect to their relative importance. It is also possible that other factors were at work that permitted quick and effective responses, and these should also be examined.

We propose to start this study by looking into fifteen to twenty cases where the response to negative feedback has been relatively efficient: the VW Rabbit, the GM X-models, the Saab front-wheel drive, Honda's "modern" cars, the Ford Escort, one or two new British cars, the astonishing improvement in the reliability of the Toyotas and Datsuns, and so forth. With the cooperation of the firms involved, we would like to understand, as best possible, the factors that made for relatively efficient responses. Something might also be learned from the less efficient responses (e.g., why has the Jaguar car always been frightfully expensive to maintain?). However, we believe that it would be wise initially to concentrate on the more successful cases. In these cases, our aim would be to explain, as well as possible, the factors that have made for success. Did the feedback get into the organization at a point when swift action could be taken? Did the building of experimental automobiles play an important role? How decentralized was the decision-making process? What role did subcontractors play? How important a factor was tooling lead time? What role did flexible tooling practice play? When firms, like Honda, completely separate R&D from their production activities, what advantage are they provided in anticipating negative feedback and how do they go about making the transition from R&D to production activities? How does VW transfer knowledge from its experimental car to its production cars?

These specific questions are also covered by a more general question: to what extent is the ability of the industry to respond to negative feedback limited by its production orientation, and what are the tradeoffs involved? Furthermore, we would also like to know to what extent the crises the firms experienced resulted in more or less permanent changes in their methods of operation? For example, in what respect is the present VW Company different from that which produced the Beetle?

Finally, as was pointed out in detail previously, we propose to examine the role price competition may have had in Japan in creating incentives for rapid improvements in productivity in the automobile industry. To what extent did Japanese automakers face large risks in market share losses as a result of price or quality competition (in which sharp price constraints were in operation)? In turn, what role did these competitive risks play in speeding rapid productivity gains?

These studies may shed light not only upon Japanese productivity achievements in the automobile industry, but in productivity achievements in the Japanese economy in general. Moreover, by researching the adaptability--or, more broadly speaking, the dynamic efficiency--of the automobile industry, we would be studying an issue which, it can be assumed, will be regarded as increasingly important in all industrial countries; these countries are faced with common problems of generating new opportunities, and creating in existing firms the ability to make an adaptive response to those opportunities. Hence, it is of crucial importance to better understand what factors limit the effectiveness of such responses.

As far as the automobile industry is concerned, the big question is this: Can individual companies so structure themselves as to achieve a high degree of overall success in bringing about significant product and process innovations and in making cost-competitive and reliable products?

NOTES

1. Burton H. Klein, "A Theory of Dynamic Competition" (to be published in the Encyclopedia of Economics and Business). Copies available at the Massachusetts Institute of Technology, Center for Policy Alternatives.

2. Ibid.

3. The mathematics employed in developing the model that predicts the evolution shown in Figure I is discussed in the above article. From a broad conceptual basis, the thinking is closely akin to that employed in quantum statistics. However, to obtain statistical results, a Poisson distribution was used.

4. James M. Utterback, Dynamics of Innovation in Industry, Massachusetts Institute of Technology, Center for Policy Alternatives (forthcoming).

5. Burton H. Klein, "Hidden-Foot Feedback: Wellspring of Economic Vitality," Technology Review, October 1980.

6. William J. Abernathy, The Productivity Dilemma, Baltimore: The Johns Hopkins University Press, 1978.

7. Ibid.

8. Raymond Vernon, "International Trade and International Investment in the Product Cycle," Quarterly Journal of Economics, May 21, 1966, pp. 190-207.

9. Alfred J. Sloan, My Years With General Motors, New York: Doubleday and Co., 1964, p. 265.

10. Ibid., p. 429.

11. An International Perspective on Automobile Regulation: Public Policies and Technological Responses, Massachusetts Institute of Technology, Center for Policy Alternatives, April 1981, CPA-81-18.

12. J. M. Juran, "Japanese and Western Quality--A Contrast," Quality Progress, 1978.

13. Lawrence White, The Automobile Industry Since 1945, Cambridge: The Harvard University Press, 1971.

14. Abernathy, Harbour, and Henn, Productivity and Comparative Cost Advantages: Some Estimates for Major Automobile Producers, Harvard University, Harvard Business School Working Paper, December 21, 1980.

15. Klein, "A Theory of Dynamic Competition."

16. Lawrence White, The Automobile Industry Since 1945.