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TECHNOLOGICAL CHANGE IN U.S. AUTOMOBILE INDUSTRY: ASSESSING PAST FEDERAL INITIATIVES

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16. Abstract

Government intervention in industrial activity has become more intense in the last decade. Unfortunately, the term intervention is often used in its narrower sense and equated with regulation. This report argues that there are at least two other dimensions to government intervention, viz., technology creation action and market modification action. The former, which seeks to induce change through the creation of superior new technologies, is designated as "technology push" intervention. Whereas, market modification action and regulation (which really is a part of a more generic intervention called "product characteristic intervention") seek to induce producers to create new products or modify existing ones. This process is termed "technology pull."

Technology push and Technology pull are independent but complementary actions; and differing balances between the two types of actions has major significance for the nature and rate of technological innovation. This report presents a framework relating combinations of the above actions to their joint consequence for technological innovation.

The report studies the pattern of past Federal initiatives in the auto industry and the effect of these initiatives on automotive performance. The initiatives and response to them are explained in terms of the framework. The report suggests that the present mix of Federal initiatives can entrench technology; and should radical innovation be desired in the industry a different set of Federal initiatives would be required. Some policy options are explored.

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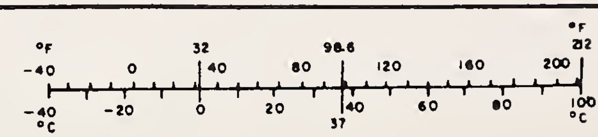
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	squsre centimeters	cm^2
ft^2	square feet	0.09	squsrs meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square milss	2.6	squsre kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inchss	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	scres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

In the future, further reductions in fatalities, fuel consumption and emissions due to automobile use will be needed. To insure that these goals are achieved, it is necessary to understand more thoroughly the role of Federal initiatives and regulation in encouraging the development, implementation and adoption of innovative automobile technology. The current study provides an important link in addressing these questions. It examines the pattern of past Federal initiatives in the automobile industry and the effect of those initiatives on innovation. In addition, a framework is developed for assessing the joint consequences of Federal technology creation and market pull initiatives on the diffusion process.

This work was initiated as part of the Auto Technology Program at the Transportation Systems Center, under the sponsorship of William Devereaux, Office of the Secretary of Transportation. During the conduct of this study, program responsibility was transferred to NHTSA, the National Highway Traffic Safety Administration. The work was completed with partial funding from the Implementation of Innovation by the Motor Vehicle Industry Program. The technical monitor for the study was Dr. Bruce Rubinger.

ACKNOWLEDGMENTS

Although the authors take sole responsibility for the conclusions and recommendations that are contained within this report, they wish to both acknowledge and express their appreciation to many other individuals and organizations who made important contributions. In particular, Bruce Bubinger and Robert Ricci of the Transportation Systems Center, U.S. Department of Transportation, provided invaluable guidance in establishing the direction of the study in its conduct and in identifying and acquiring the necessary data. The contributions of Richard John, also of the Transportation Systems Center, and William Devereaux, of the U.S. Department of Transportation, are also acknowledged for their constructive role in setting the overall context of the research.

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1. Introduction

This report examines the effect of government action on technological change in the U S automobile industry. The intent of most Federal action in respect to the automobile has been to bring about socially beneficial technological change in respect to specific performance characteristics. Beginning with Public Law 84-159 in 1955, a series of government actions involving research and development (R&D) programs, incentives, and regulatory standards have sought to improve the environmental effects, safety, and fuel economy of automobiles. The rapidity and severity of these programs have caused the automobile industry to be described as the most recently regulated industry. In many instances new technology requiring innovations has been introduced to meet new Federal goals. U S -produced automobiles have been significantly changed and improved through these programs and even more extensive changes can be anticipated as existing regulations are fully implemented.

Although the achievements have been substantial, there are also reasons for concern. The administrative costs of Federal programs are high. As a nation we now seem no closer than in the 1950s to the adoption of fundamentally new technologies that might solve our emission or energy problems rather than offer incremental improvements. The major thrust of Federal initiatives seems to be focused increasingly on product regulation to the exclusion of other options. While past programs have worked, they may not meet future needs, and serious attention is needed to identify the types of Federal action that will be most effective and appropriate.

The purpose of this study is to examine the effectiveness of government action in terms of the outcomes that have been sought. The concern of the study is to inquire into those types of government-industry interactions which promise to bring about intended change in an effective form. The appropriateness of government or industry goals in respect to long-run national needs are not considered in this report.

Different types of actions including research and development programs, incentives, and regulatory standards have been undertaken by Congress and Federal agencies to stimulate technological change in the automobile in respect to specific attributes of performance such as air pollution, safety, repair costs, and more recently, fuel economy. An abbreviated chronological listing of the major laws that affect the performance of the industry is summarized in Appendix A. The process of evolution of these laws is by itself an interesting tussle between the industry and the government.

The industry does not seem to have favored performance regulations in the form they have taken, while at times being in agreement with the Federal Government on the need for regulation and many of the objectives guiding these legislations. Many managers in the industry acknowledge the need for pollution control regulation and certain safety regulations, where there are few competitive incentives to spur innovation, but would have preferred a more nearly voluntary approach in improving automobile fuel economy. Some observers believe that the industry is not likely to make socially beneficial improvement without regulation, pointing out industry disagreement and delays in accepting even mandatory standards. Others question this argument on grounds that the standards themselves have often been inappropriate and unrealistic. The viewpoints of two observers help to clarify the basis of this controversy and also to illustrate the nature of discussions among many who are involved in the regulatory process.

Eugene Goodson[1] of Purdue University, who has studied industry responses to regulation in some detail, questions the ability of the industry to have done much voluntarily in any of the above three areas. In fact, he suggests that "from the data on the response of the industry to past regulations, there is ample evidence to doubt compliance with the mandated program." He goes on to document delays in industry response to Federal regulations, in almost all cases, as evidence that the industry resists Federal initiatives for product improvement in these areas.

Goodson's implicit thesis is that the standards were appropriate, the technology was available and the problems arose because the industry lacks the incentives to respond to Federal standards in a reasonable time, therefore requiring amendments to these standards. He concludes that without these Federal pressures the industry performance would have been worse.

In another study Howard Bunch[2] from the University of Michigan questions Goodson's assumption that delay in adherence to Federal standards by the auto industry is evidence of its poor response. He documents the industry's support of some of the earlier safety standards and suggests that in other cases the proposed standards were improper in several ways. Using safety standards as an illustration, he identifies four major problem areas with Federal safety regulation.

a. Lead time requirements

Bunch seems to support the auto manufacturers' contention that the time available for implementing a Federal standard is often inadequate and ignores the complicated procedure which the industry must follow to introduce change efficiently in industry's mass production vehicles.

b. Review of cost/benefit relationships

Whereas standards are developed on the basis of proforma cost/benefit relationships, the problem with the regulatory process is that there is no continuing process of evaluation of the imposed regulations. Bunch argues, that "as a result, there is a tendency among the regulated to strongly react to any suggestion of rulemaking; they see such rulemaking as the beginning of a non-reversible process."

c. Relationship between company size and the cost of implementing a standard

Bunch states, that "there is reason to suspect that there may, in fact, be a per unit cost differential associated with safety regulation compliance. If so, then an argument could be made that safety regulation, per se, is a restraint to competition, in that it tends to make the small producers even less competitive."

d. Pre-implementation research and development

As Bunch observes, "One of the major problems associated with effective standards development and implementation has been vagueness in specifications, test procedures, and benefits. Much of this problem could be eliminated, it is believed, if there were more effective pre-implementation research and development" (by the government).

Bunch, like Goodson, emphasizes that the industry's response to Federal regulation is tied to market forces. He observes that "societal attitudes and economic conditions are a most important factor in the industry's responses to proposed rulemaking."

The disparate conclusions which these two men reach by analyzing different data sources nicely illustrate the problem which one faces in attempting to improve the current regulatory process. Goodson's data on government initiatives and industry response may reveal much about bargaining behavior and the appearance of "foot dragging" which it gives, without doing much to clarify the reasons for this behavior. Bunch's findings seem to confirm that there is often good reason for the industry to "drag its feet" so to speak and bargain for better regulation.

It is important to understand the process of rulemaking and response to it, and to clarify the desired roles in the give and take of the regulatory process. At the same time it may be that larger issues are at stake, in respect to the development of improved technology. These issues are often obscured by excessive attention to just the process of implementing regulatory standards. Is the overall form of Federal initiative appropriate to longer run national goals? At this broader conceptual level, the question may be whether the mix of Federal incentives and regulatory action is most appropriate to future needs. Would some other balance between Federal R&D regulatory action or market incentives be more appropriate in stimulating the needed form of technological change?

A study[3] of Federal R&D programs related to automotive technology, recently completed at MIT, suggests a much lower government commitment to R&D than to regulatory action. The reason for this, so frequently expressed by government policymakers, is that the U.S. automobile industry has the money to do its own R&D. Industry should do it, and conserve Federal funds for fragmented and disadvantaged industries. While convincing at first thought, this argument should not be used to lightly brush away a review to determine the most effective options.

What industry can and should do in respect to issues like R&D investment and innovation can no longer be judged independently of government action. In the presence of increasing regulation on several fronts, the actions of industry and government need to be considered as interdependent. If a radical change in technology is necessary, say to reduce dependence on foreign oil or to reduce environmental impact, then the full range of instrumental policy including government R&D investment should be considered. If the benefits to society from major product innovation (a superior electric car, for example), greatly outweigh the resource costs then the full range of options to bring about innovation should be considered without the prejudice from simple generalization.

The Federal option to stimulate innovation and technological change seems to be jointly formed from three types of forces that the government influences directly or indirectly:

a. Federal support for research and development underlying technology creation.

b. Federal and state government regulatory intervention.

c. Market forces - a combination of change in societal attitudes and economic conditions.

Together with individual variations reflecting each auto manufacturer's attitudes, the manufacturer's response is in a sense determined by the equilibrium of the above forces. Both Goodson and Bunch have looked only at the process of regulatory intervention. Others have similarly focused on a single influence of change. It will be our endeavor to suggest and apply a framework, incorporating all the three forces referred to above.

The methodology underlying this work proposes to examine Federal action and technological response from a perspective that highlights joint consequences. In the next chapter a general framework is suggested that provides an initial step in analyzing joint effects, highlighting interaction among different types of Federal action. This framework is illustrated using data and analysis from earlier studies that have examined past Federal action and outcomes that arise both from within the transportation sector and from other industries. Chapter 3 of this report outlines the course of recent Federal initiatives within the context of this framework. The effects of these actions on the automobile are then examined in Chapter 4. The final chapter of the report applies the framework to interpret current actions pertaining to the U S automobile industry. This analysis helps to distinguish between those aspects of Federal action that have been particularly useful in stimulating beneficial technological change and other actions associated with lower rates of success. Chapter 3 includes a special analysis of Federal R&D programs relating to automotive technology during the years 1973-1977, which offers insight into the conduct of Federal R&D. From these analyses conclusions are drawn with respect to types of Federal action that most significantly induce technological change.

2. Toward a Framework for Analyzing Federal Initiatives

The balance and intensity of government intervention in industrial activity has shifted decisively over the past decade.(4) This change in the nature of government action is of vital importance to technological progress and economic development in the United States since government policy sets the context for industrial development.(5) Some contend that recent changes in the nature of government intervention have begun to retard our capability for technological innovation and productivity improvement. The problem is too complex and the ramifications of recent changes are not sufficiently understood to support such sweeping generalizations, but it would seem to be clear that the implications are of such importance to warrant careful inquiry.

One important form of intervention, Federal investment in research and development (R&D), has declined both in real dollar terms relative to prior years and relative to the investment ratios of other major developed countries.[(6)] Even though the decline is rather modest it is significant because of the role that Federal R&D investments play in stimulating innovation in the U.S. economy.

Over the same time period, regulatory intervention has increased dramatically. Traditionally, intervention in this form has arisen from public concern about the effectiveness of a free market in producing certain kinds of goods and services efficiently and equitably. The thrust of regulatory intervention now seems to have extended far beyond this narrow focus, however, to become a pervasive factor in broadly shaping industrial performance.

A recent comparative study of regulated industries provides a perspective on possible implications of this change in the mix of Federal initiatives. The Brookings Institution[(7)] examined technological change in four important regulated sectors: electric power, telecommunications, civil air transport, and surface transport. The study concludes, that "regulation in railroad and truck transport almost certainly slowed and distorted the pace and pattern of technological change.... In contrast, the net impact of regulation on the pace and pattern of technological change in telephonic communication has probably been positive, or at worst neutral. The structure of the industry, completely dominated by a single firm (AT&T), that is both horizontally and vertically integrated, is the most important factor in explaining this." In the case of electric utilities and civil aviation, the study concludes that the strong, Federal support for R&D has helped in sustaining a rapid pace of technological change. While the electric power industry had done almost no R&D, it had "relied on the equipment industry and other suppliers and on the Federal government to support R&D." In the case of civil aviation, "major technical advances have usually come from efforts supported by the military to improve military aircraft capabilities."

The findings of this study reinforce the notion that regulatory intervention plays a vital role in shaping technological progress but one that defies simple generalizations. The efforts apparently depend on several conspicuous factors such as the type of regulation, the industry's technology base and its structure, etc. Perhaps of equal, if not greater, interest, however, is the subtle interplay between Federal intervention in the form of R&D investment and intervention in the form of regulation. These interrelationships suggest that it may be useful to view these two forms of intervention as interdependent rather than as separate policy instruments through which different national goals might be pursued.

At a time when the mix and intensity of Federal intervention has shifted dramatically there is a need to better understand the joint effects on technological progress. For the present purposes it is instructive to identify and evaluate three types of action which can then be further grouped by their effects as either technology pull or technology push initiatives, so that joint effects can be explored.

Technology Push Actions:

a. Technology Creation Actions which involve the government directly in supporting the development of new technology or the modification of existing technology.

Technology Pull Actions:

b. Product Characteristic Interventions that shape product innovation either directly or indirectly through a variety of actions ranging from persuasion (jawboning) to regulating product standards.

c. Market Modification Actions that induce innovation by market incentives through changes in price, the indirect effects of regulation in related industries, modifications in the market structure, or direct government purchases.

The second and third categories rely on designing market mechanisms or incentives to induce producers to create new products or modify existing ones. We refer to such a process of induced change as "technology pull." R&D programs which seek to induce change through the creation of superior new technologies are designated as "technology push" initiatives.

2.1 Technology Creation Actions

The costs, timing of payoff and implications of the outcome are distinctly unique for different types of technology creation actions. At one extreme there is basic research which is undertaken to support the creation of new knowledge. As Kenneth Arrow(8) and Richard Nelson(9) have concluded, the ultimate payoff to society from such work is very high relative to cost. On the other hand, the payoff is uncertain and long in coming. A recent National Science Foundation study(10) of ten highly beneficial innovations, including products like the Heart Pacemaker, Hybrid Corn, and Magnetic Ferrites, successfully traced the essential underlying research events. The results show the vital contribution of such work but they also highlight the long gestation period. Of the 533 significant events (or breakthroughs) underlying the ten innovations, 72% were the fruits of research (dividing 34% for non-mission-related work and 38% mission-related work) while only 26% arose from development. At the same time the period for innovation alone, from first product conception to commercial application, averaged over 19 years, and half of the essential non-mission research events dated back 30 years prior to commercialization. These and other related studies show the enormous importance of basic research but they also graphically point out the uncertainty as well as the difficulty in analytically justifying such investments and in relating the ultimate contribution of any given basic research project to a previously identified product objective.

The other extreme includes programs which involve direct government expenditures for the development or production of a product that will be placed into immediate use. The best example of this is in equipment or ordnance production for the Department of Defense or for NASA. Even for products destined to serve the private sector, (like nuclear fuels or satellite communications), there are instances of direct "technology push" investment in such "close to market" technology creation activities.

The majority of Federal expenditures in the technology push category, however, fall between these two extremes. Demonstration programs, mission-oriented R&D programs leading to prototypes, etc., are the types of actions that are most frequently encountered in practice.

Figure 2.1 lists six different types of technology creation actions, arranged in an order that suggests differences in their characteristics. Six different types of actions from research to define criteria and needs to

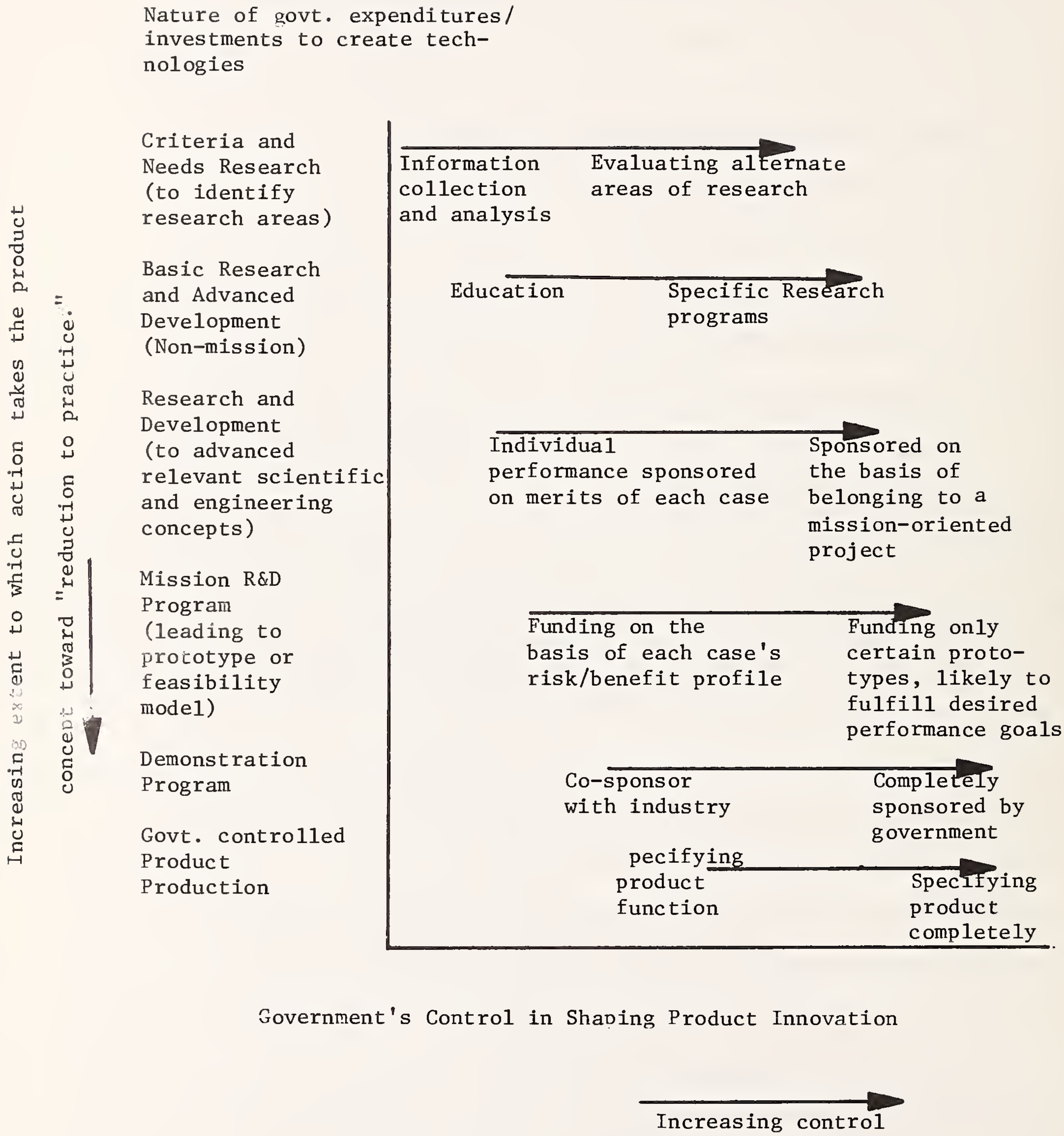

FIGURE 2.1 TECHNOLOGY CREATION ACTIONS

direct production are described along the left-hand side of the figure. The rank order of each action on the page is intended roughly to suggest the increasing extent to which the characteristics of the final product are determined by the specified type of R&D program. Stated another way, the order concerns how far the action takes the product concept toward "reduction to practice."

Basic research is shown as the most removed from product application while production or control over production quite obviously takes the concept closest to practice. The scale going across the page on the other hand shows the increasing extent to which government control over the action places the government itself in a position to shape the product innovation. This horizontal scale also reflects different intensities of government involvement within each type of action. For example, a demonstration program with a minor percentage of government funding or control still may not greatly influence the product, since the outcome will be shaped significantly by normal economic and market incentives. On the other hand, a demonstration program that is completely funded by the government, as depicted by the right-hand extreme on the scale, represents a high degree of government control over the new product.

The criteria for rank ordering each possible government action and the intensity scale within each activity are obviously closely related. The step-like graph in Figure 2.1 illustrates this relationship. For different types of government action along a left to right downward sloping diagonal, down the vertical scale and towards the right on the horizontal scale, there is increasing governmental influence in shaping the final product.

Other changes will also typically accompany the movement down the diagonal: whereas the action's influence on the product becomes more immediate and visible, the cost per program also grows significantly. In a sense moving down the diagonal from the upper left to the lower right of Figure 2.1 involves increasing government support for immediate technological change.

2.2 Product Characteristic Interventions

The array of possible government regulatory actions (Figure 2.2) ranges from relatively weak persuasion to the fine detail of controlling the specific technology of a product through regulation. While the latter is potentially the most powerful option for immediately influencing product technology, its long-run effects on technological progress are still controversial.

Rubenstein and Ettlie's recent study[11] of 32 innovations by automotive suppliers shows that Federal laws or regulations affected innovation at the detailed component level, both as the most important barrier and as the most important stimulant of change. They acted as a barrier in 47 percent of the cases and as a stimulant in 44 percent (multiple response possible). If this pattern is generalizable now when regulations are recent, there may be reason to question what their effect may be if standards are not constantly updated. A plethora of specific standards might well impair future technological progress in industry.

As in the previous figure, the movement along the diagonal represents increasing government control over changes in product characteristics.

2.3 Market Modification Actions

The several government actions that may be used to influence or direct technological change through market incentives are suggested in Figure 2.3. As with the prior category, this figure is arranged so that the diagonal suggests increasing direct government influence over the final products.

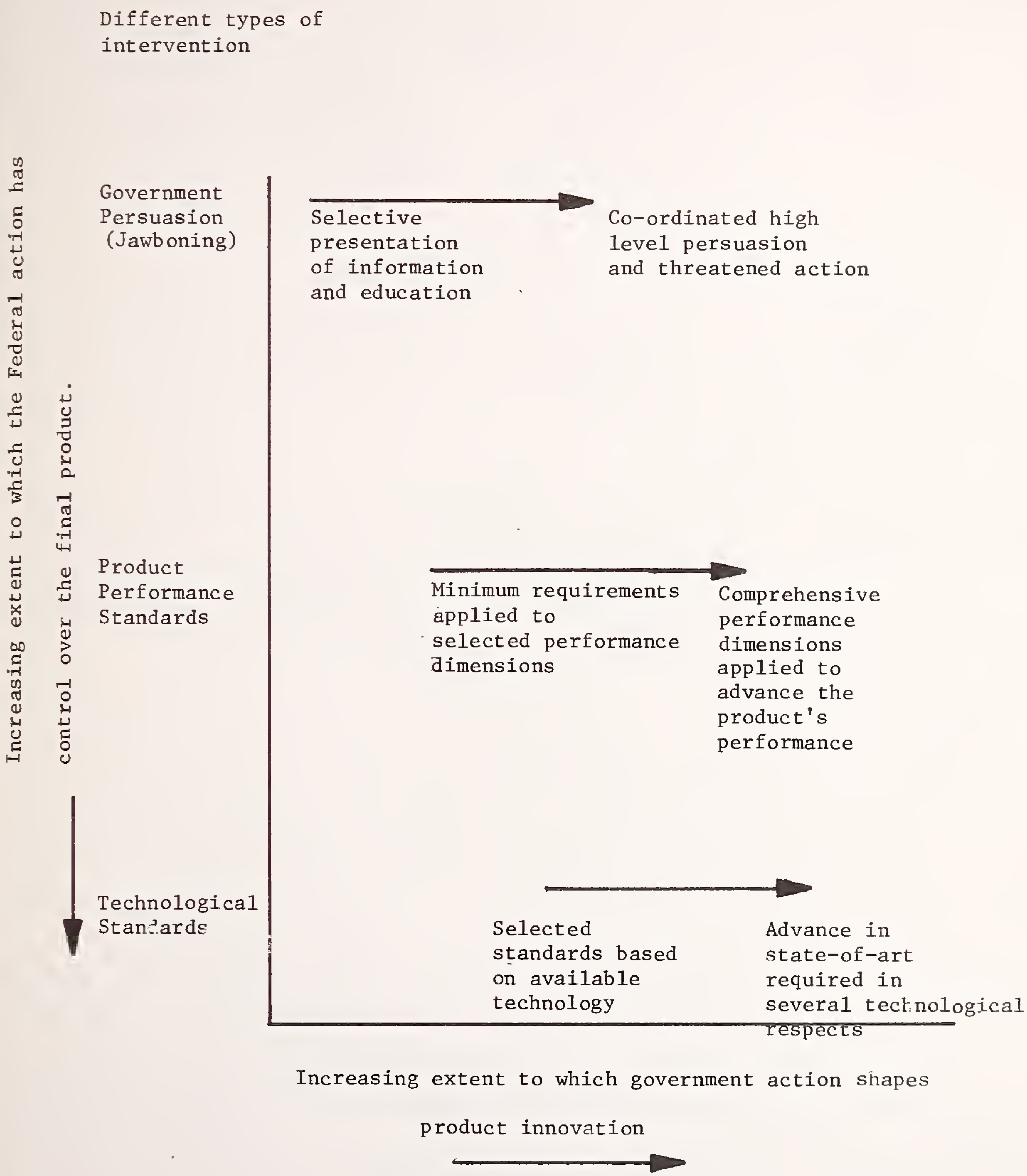

FIGURE 2.2 PRODUCT INVERVENTION

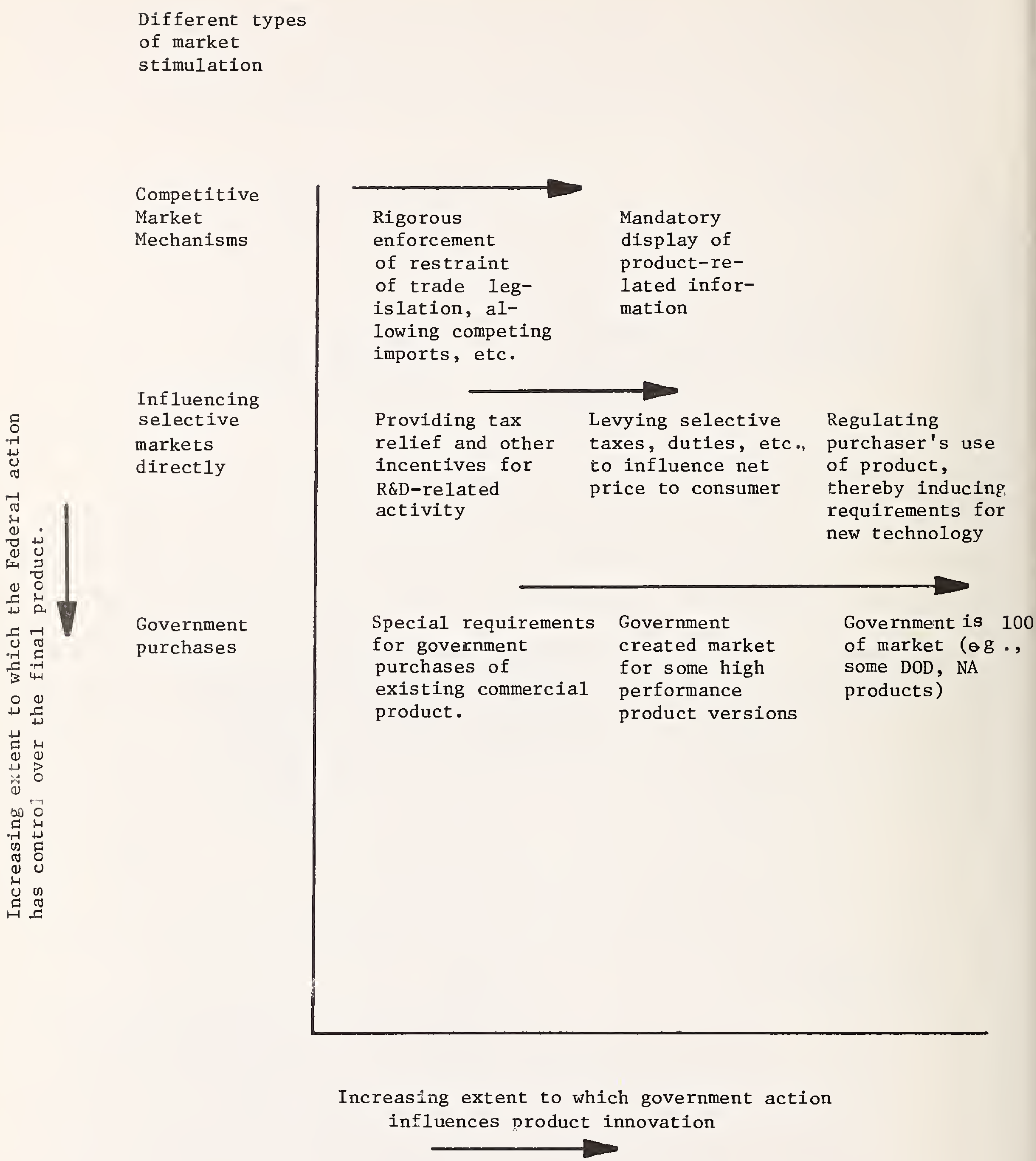

FIGURE 2.3 MARKET MODIFICATION

Rigorous enforcement of Restraint of Trade Legislation shown as the first action type in the upper left-hand corner of Figure 2.3, is expected to bring about product change through increased competition. It is shown to offer the least control because this form of action would not normally provide a mechanism for use by the government to shape the form of the technological outcome. A more competitive industry structure would place more control in the hands of traditional market mechanisms. On the other hand, actions which encourage more competition in selected areas may increase the degree of government control. Procedures which establish selective information bases for use by the market (for example, publishing miles per gallon ratings for cars) may create incentives that can shape technologies in intended directions.

Clearly the greatest potential for market modification is realized when the government itself represents 100 percent of the market. In his recent study of Department of Defense influences on innovation in the electronics industry, James Utterback[(12)] describes the important role of procurement as follows: "Defense demands have strongly focused and have tended to be the pacing element of change in the industry as a whole." His findings suggest that the government's purchases of high performance products supported innovation and the initial leading edge, entry of highly significant products like jet aircraft, computers, advanced semiconductors and even polyethylene film.

2.4 The Conceptual Framework

Three types of Federal initiatives which can provide impetus for technological change have been described above, each represented by the diagonal in one of the three figures. Taken collectively, these three forces may be used as dimensions in a conceptual scheme that can be applied to explore the effects of Federal actions in influencing technological change. Though ideally the influence of all the three forces should be considered, some major interactions are revealed when we reduce them to two, which is more practical for further representation on a two-dimensional scale. Technology creation action represents the Federal Government's direct participation in R&D. However, market modification and product intervention actions both require that firms perform the R&D in response to government action -- a technology pull response. We therefore group the three types of Federal initiatives into two categories:

1. Direct technology push actions (DTP), comprising technology creation action.

2. Indirect technology pull actions (ITP), comprising both market modification action and product characteristic interventions.

The roles of both DTP and ITP categories are more apparent when their implications are considered in an industrial context. The impetus for change within a particular industry can be described aggregately for a particular product in terms of the two dimensions discussed above, the degree of direct technology push (DTP) and indirect technology pull (ITP). The more urgent the national goal and the longer the time span of normal industry response, then the greater the political pressure for increased intensity of Federal action. The intensity of action relevant to a given product is illustrated in Figure 2.4 below. This approach will be used as a conceptual framework within which to evaluate the effect of alternative Federal actions.

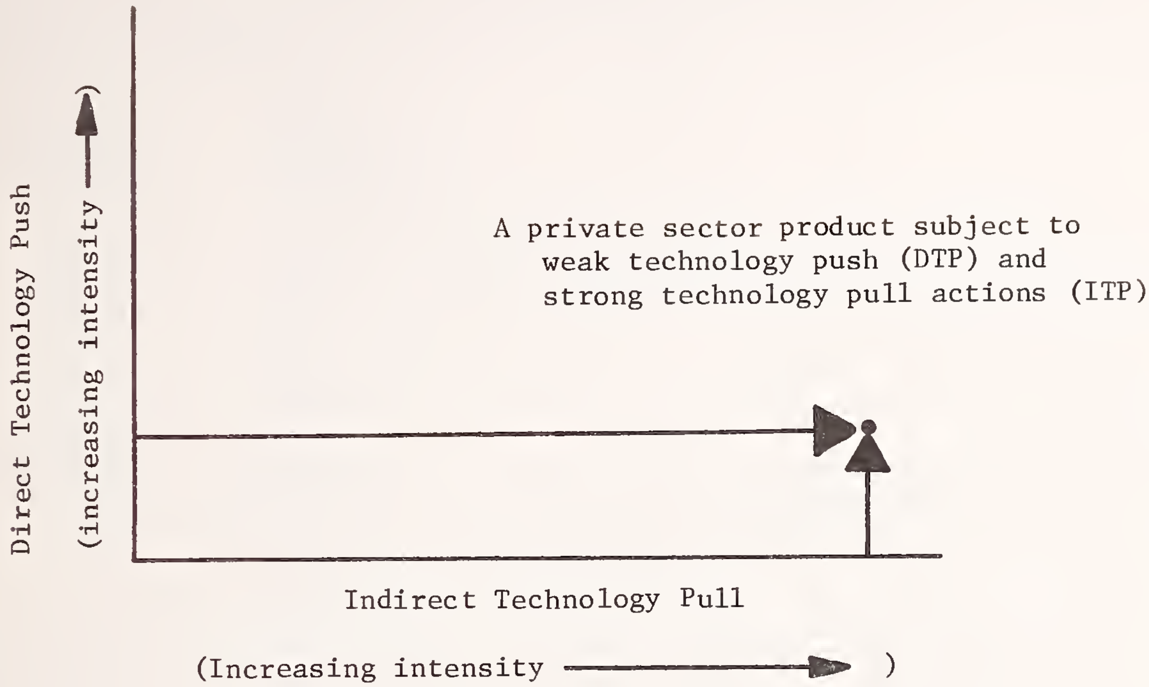

FIGURE 2.4 ILLUSTRATION OF TECHNOLOGY PUSH AND PULL THROUGH GOVERNMENT ACTION

2.5 Illustration of the Framework with Past Federal Projects

Judgments may vary widely about the effect of the two different categories of government action. Some objectivity about this can be gained by applying the present framework to recast results from a set of prior Federal projects whose circumstances are documented and whose outcomes have already been evaluated. The RAND Corporation's recent study(13) of Federally funded demonstration projects provides a useful data base for such a purpose.

A rather distinct pattern of interaction is apparent between the two major categories of government action when the characteristics and outcomes of fifteen prior Federal demonstration projects from this study are viewed from the present perspective. The fifteen cases are as follows:

Table 2.1

FIFTEEN FEDERAL DEMONSTRATION PROJECTS

Title	Approximate Cost to Federal Agencies ($000)	Identifying Abbreviation
Nuclear Ship Savannah	$100.00	NSS
Scottsdale Arizona's Mechanized Refuse Collection	0.18	REFUSE C.
Shipbuilding R&D Program	14.00	Ship R & D
Fish Protein Concentrate Plant	3.50	Fish C.P.
Haddonfield N.J.'s Dial-A-Ride	10.00	D - A - R
Yankee Nuclear Power Reactor	8.30	Yankee N.R.
St. Louis' Refuse Firing Demonstration	2.60	REFUSE F.
HUD's Operation Breakthrough	72.20	BREAKTHRU.
Morgantown W.V.'s Personal Rapid Transit	61.00	PRT
Veterans Administration's Hydraulic Knee Prosthetic Devices	0.91	H. Knee
Poultry Waste Processing	0.20	PWT
Chicago's Expressway Surveillance & Control	5.70	Expressway S.
Commercial Maritime Satellite	8.20	M. Satellite
Point Loma Saline Water Conversion Plant	2.30	Salt W.P.
Tri State's Automatic Vehicle Identification	0.05	AVI

RAND, as part of its evaluation, assessed both the immediate success of each project and its subsequent success in achieving diffusion of the concepts and technology. For the present interpretation, the success of each project in stimulating diffusion (the second measure) is the basis of judgment about the outcome.

The characteristics of each project, as described in the report, include: the rate of cost sharing by industry (sometimes most of the costs were borne by industry); the initiating organization; special types of control exercised by government; special stimulating factors in the environment; an assessment of initial technological and market uncertainty; the reduction in technological uncertainty which the project achieved and special institutional factors that affected the success or failure of the project. From judgments based on project histories and these data, each project can be generally positioned along the two major dimensions of government action, as described above. Figure 2.5 graphically illustrates the pattern that results when the projects are cast in such a framework.

Success or failure of each project in terms of diffusion is indicated by the type of dot on the graph. A solid dot is a success, a circle is a failure and partially shaded dots indicate some success in terms of diffusion.

Even though a continuous scale is used for each axis of the figure, it is important to recognize that the projects have been positioned judgmentally in this graph, rather than in any precise or analytic order. The illustration is conceptual since neither the data nor the definition of the scales are sufficiently precise to support analytic treatment. The framework and data however are considered to be adequate to partition the cases into high and low categories; and, as will be seen subsequently, this treatment is quite sufficient to support a few interesting, if speculative, observations.

2.6 The Interaction of Federal Initiatives

A definite pattern of interaction between the two categories of government action is apparent in Figure 2.5. Considering the top half alone, representing projects with stronger technology push, the presence or absence of corresponding technology pull actions would seem to be critical.

Failure is the predominant outcome in the upper left cell, where there is intense direct technology push action, but no corresponding technology pull action. This cell includes the Nuclear Ship Savannah, Operation Breakthrough, Dial-A-Ride, the Fish Protein Concentrate Plant, and Personal Rapid Transit. These projects uniformly represent situations where there were little or no changes in market incentives to encourage and support the adoption of a

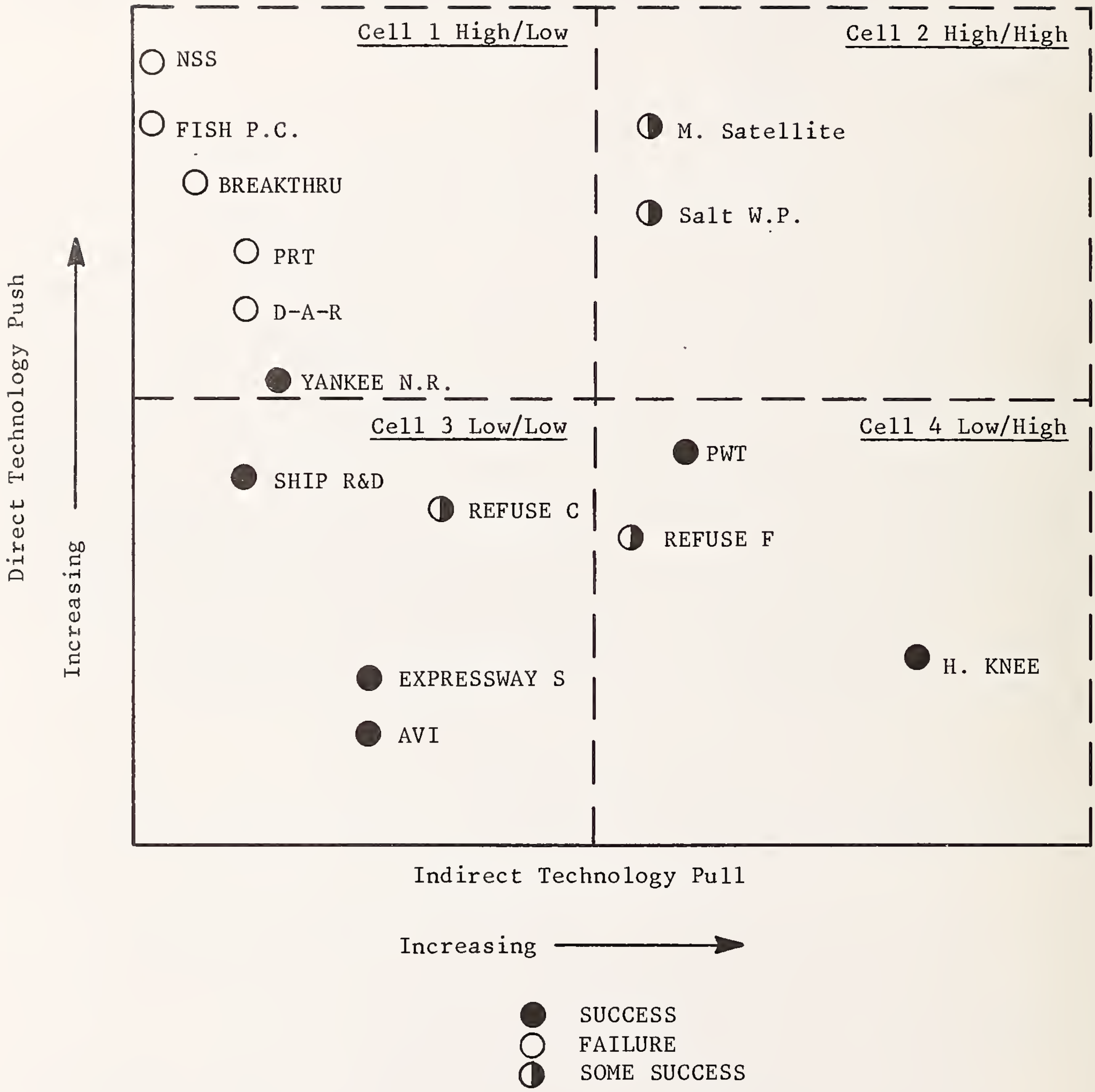

FIGURE 2.5 PROJECT SUCCESS AND FAILURE PATTERN
(Degree of Technology Push/Technology Pull)

new technology. On the other hand, for the upper right cell, (high/high) the government actually supported the market for many of these projects through procurement creating a strong modification action whether intended as such or not. The Commercial Maritime Satellite was supported through the Navy's purchases of navigational satellite services and the Loma Point Saline Water Conversion Plant was actually acquired by the Department of Defense for use at a Navy base during the demonstration project.

The successful Yankee Nuclear Power Reactor appears the one exception to the pattern that is otherwise so apparent in the upper cells. Actually even in this case, from an historical perspective, the same generalization also applies. Although the market for nuclear generated electric power per se had not been altered through government intervention at the time of this project, the market for nuclear products in general had indeed been created earlier through purchases by the Atomic Energy Commission and Department of Defense. As in the other cases, the government modified or created the initial market through purchases for its own use. Beyond the issue of success or failure a second distinctive characteristic of the two upper cells is that they are populated by radical products or, if successful, they led to major innovations. These projects envisioned major changes in practice within the industry where they were to apply. In doing so new organizations were stimulated to enter the field. The demonstration projects here may be characterized as big gambles to introduce major changes.

The two lower cells, represent situations where the government has been less venturesome in a technology push sense. The ratio of success appears much higher. From the case data it would seem however that the innovations which result are much more incremental than for the upper cells.

Cell four representing low intensity technology push but strong technology pull (low/high) includes three projects. The Poultry Waste Processing and the Refuse Firing Demonstration projects both represent successful attempts to solve waste disposal problems under conditions of tightening environmental controls and concerns. Both also represent projects that were initiated by organizations unrelated to the Federal Government but closely linked to the problem. They also did not rely heavily on Federal funds. In the Hydraulic Knee case the Veterans Administration used its market for the project to stimulate the innovation and dealt skillfully with the broader problems of market acceptance. In all three cases RAND characterized the initial technological uncertainty as low to moderate.

The cases in cell four seem to represent situations where the normal process of innovation has been accelerated through government action that directly or indirectly affected the market. These changes stimulated organizations which were already functioning within the respective fields to propose new solutions and seek out Federal R&D support. The results were a successful acceleration of incremental innovation through established organizations.

Cell three (low/low in Figure 2.5) includes four mostly successful projects involving municipalities, shipyards, the Tri State Port Authority and state governments. In comparison with large, technology-based, industrial enterprises these types of organizations are often considered technologically less active. Certainly they cannot rely on the same level of industrial infrastructure that was present to support innovation in the prior health and food processing industry cases.

In effect the presence of a low intensity Federal program would seem to have been a catalyst which helped to create the necessary infrastructure to support technological innovation. In fact, according to the RAND report, in the one partial success in this cell (Scottsdale's Mechanized Refuse Collection), the project was limited in its achievement largely because there was insufficient industrial infrastructure to successfully refine and transfer the concepts to applications in other cities.

Direct Federal Technology Push		High (Indirect Technology Pull)	Low (Indirect Technology Pull)
	HIGH	1 Extreme Risk (High Failure Rate)	2 Radical Innovation (High Risk/High Payoff When Successful)'
	LOW	3 Normal Process of Industrial Innovation - Enabled (Low Risk and Moderate Success)	4 Incremental Innovation - Accelerated (Low Risk and Moderate Success)
		HIGH	LOW

Indirect Technology Pull

FIGURE 2.6 INTERACTION OF FEDERAL ACTIONS

2.7 <u>Implications from Application of the Framework</u>

The joint effects of direct government technology push and indirect technology pull, as discussed above, are illustrated by the two by two matrix in Figure 2.6. Each cell is summarized in turn.

1) <u>Intense Technology Push, Weak Technology Pull</u>. The troublesome failure to success pattern that is so apparent in the high/low cell is not just an artifact of the particular sample of cases that has been used to illustrate the present framework. Earlier experiences with other programs like the Eisenhower administration's Atomic Aircraft Program, the Breeder Reactor, or the Supersonic Transport, are suggestive of the present pattern. This does not imply that all Federal programs which undertake a technology-based initiative are failures. From a broad perspective the space program might be characterized as a Federal action of this type and on a different level so might TVA and the original Atomic Energy Program. The outcome

of these programs has certainly been important but, even so, successful industrial diffusion has come very slowly. The programs where technology push alone has been successful seem to have involved funding levels measured in fractions of the Gross National Product.

On balance it seems appropriate to characterize normal projects within this category as extremely risky. This does not mean they should not be undertaken. The benefits to society may greatly outweigh the cost even when adjusted for risk.

2) High Technology Push, High Technology Pull. This cell is perhaps the most interesting. Beyond the present sample this category represents the environment of origin for many major innovations that have strengthened the U.S. economy in the post-World War II era. For products like the computer [14], the jet engine [15], and advanced semi-conductor devices [16] among others, as well as the present cases, the Federal Government has been a major factor in the innovation process through its joint initiatives in market modification and direct investments in technology. In particular within the market modification category, government procurement seems to have been critically important in creating a market for advanced technologies at a time early in their life cycles when prices were very high vis-à-vis competitive technologies, and the range of applications was limited. Such support during a technology's infancy helps to nurture evolutionary development to the point that broad-based commercial applications are economically justified.

Government action within this category was apparently not only a factor in major innovations in the 1950s and 1960s but it also seems to represent an important influence for many less well-known innovations in the more distant past as well as the present. In his classic study of the radio industry McLaurin[17] reports that government support was critical in the early development of that industry at the turn of the century.

Today we find evidence of innovative stimulation through the combination of government investment in technology and procurement even in a relatively mature industry like motor vehicles. A particular example of this is the FMC Corporation's New Choker Arch High Speed Logger, which is reported to have recently increased productivity in commercial logging operations. This equipment is claimed to operate at twice the speed of conventional tracked loggers through the use of a torsion bar suspension system that was originally developed by FMC for the U.S. Army's M113 Armored Personal Carrier. Data concerning this innovation suggest that both military and commercial customers have benefited from technology transfers within the divisions of FMC. A factor that seems to be important to innovation and successful technology transfer in this case is that the firm which undertook government R&D for the Department of Defense also had the capability to serve industrial markets. The significance of this factor should not be overlooked under present circumstances where there is a definite need to infuse advanced technology in the automobile industry and the history of successful technology transfers is clouded.

The FMC logger case also focuses attention on an important relationship between government action and industry infrastructure. This same aspect is also evident in the previous RAND data.

In the case of the Mechanized Refuse Collection, difficulties arose because such industrial infrastructure was lacking. Successful diffusion of an effective concept was thwarted because the relevant segments of the equipment supply industry were not involved in the innovation.

Government action in stimulating technological change is apparently most effective when it directly influences the manufacturers of product components that embody the technology. It was important for both the government and commercial markets that FMC was a principal source of the component's technology. These ideas are consistent with the conclusions that Burton Klein [18] has drawn from his studies of government R&D policies underlying the successful development of high performance aircraft in the United States. He argues that to effectively promote a high rate of technological change it is important to support the development of innovative <u>components</u> by skilled manufacturers <u>before</u> advanced performance requirements are rigidly established. It would not seem sufficient to undertake only the most appropriate type of technology creation action. That action must also involve firms within the industry infrastucture that can serve the necessary markets with the component technology.

3) <u>Weak Technology Push, Weak Technology Pull</u>. The effect of Federal initiatives in the third cell would seem to enable the normal process of industrial innovation in industrial environments where it is otherwise retarded. In terms of government policy goals this may be an important achievement. In some industries, notably segments of electronics or high technology segments of the medical equipment

industry, existing competitive conditions already induce a high rate of innovation. In other industries that are highly fragmented, or technologically stagnant, such stimulus may be needed to encourage innovation. In such cases intense regulatory or market modification actions would probably not have a favorable effect. It is encouraging to note that moderate policies in these cases acted to stimulate higher levels of innovation.

4) Weak Technology Push, Strong Technology Pull. The effect of Federal initiatives which induce strong technological pull relative to technology push would seem to be an acceleration of technological change but through incremental innovation. The emphasis in this mode is on perfecting and refining established technologies rather than innovating with new ones.

The innovations in this cell that were analyzed earlier, acted to perfect and refine approaches and equipment that had already been introduced. This pattern of response would seem to be more pervasive than might be suggested by just the few cases that have been presently considered. Solutions required by safety, water and air pollution regulations have frequently been sought by capital equipment manufacturers through add-on components, minor adaptions and incremental changes. The effect is most pronounced in mass production industries, like automobiles, where the cost of change is very high.[19] One industry where product innovation is competitively important, that has recently come under increased regulation, is pharmaceuticals. Emerging performance trends here suggest that government action may have increased the cost of major technological change in the product and thereby slowed it.[20] A similar chilling effect of regulation on major automotive innovation was predicted by Jacoby and Steinbruner in their book, Clearing the Air.[21] They made the point regarding pollution control and the internal combustion engine. The argument is that intense pressure for rapid change acts to increase the risk of failure from undertaking new approaches and thereby causes entrenchment in established technologies. In other words the prospects for the introduction of a radically new technology are likely to be weakened by intense pressure for rapid change. Another reason for this entrenchment phenomenon is illustrated in other industries by patterns of competitive responses by established firms to market invasions by new products. When established firms find their traditional markets invaded by radical new products, as did mechanical calculator and vacuum tube producers some years ago, the response is often to compete through cost reductions and incremental innovations in established technologies. Incremental innovation is accelerated under this pressure; and in some cases the current advantage of established technologies over prospective new competing ones may be actually widened even further in the process.[22] Intense pressure for modification can therefore postpone the application of a technology that might be superior in the long run.

2.8 Summary

The matrix presented in Figure 2.6 constitutes a framework which focuses attention on the joint effect of two major categories of government action. The effects suggested by the different cells must be considered as tentative, however, until a more rigorous study using precise scales and measurement can be conducted. Work is also needed to evaluate the components of technology pull actions, separating out the effects of product intervention from indirect market modification actions. Despite these limitations, however, the patterns revealed by the framework are sharp and suggest major differences in implications that are important in policy formulation.

Differences in outcomes among the cells show two principal effects: a difference in the type of innovation that is supported by the various environments and a difference in success rates of the actions. The conditions inducing the most rapid rate of incremental innovation or progress within established technologies are apparently much different than those which nurture radical new technologies. There need be no presumption that radical change is better, only that the consequences for long range economic progress are different than for steady evolutionary progress. This framework will be applied subsequently in a more specific appraisal of action taken with respect to the automobile industry.

3. The Pattern of Federal Initiatives

This section briefly reviews the sequence of recent Federal initiatives in respect to the automobile industry. The intent is to identify patterns within the technology push and pull categories in terms consistent with the framework that was developed in Chapter 2. The effects of these initiatives in advancing automotive performance is considered in the subsequent chapters. Implications for policy making and further research are discussed in Chapter 5.

3.1 R&D Programs - The Technology Push Option

The scope and content of Federal research and development (R&D) programs relevant to automotive technology are difficult to identify. Projects are carried out by different agencies under different funding sources while reporting on them is fragmented and difficult to compare. In the face of these difficulties a special approach had to be developed to define even rudimentary characteristics. A profile of relevant Federal R&D activity has been developed by compiling and analyzing a broad sample of automotive-related R&D projects. This sample of R&D projects was prepared from two sources. The first was the Inventory of Energy Research and Development 1973-75, prepared for the task force on Energy Research Development and Demonstration of the Subcommittee on Science and Technology, U.S. House of Representatives (Volume II). The second was the larger Smithsonian Scientific Information Exchange computer-based file of R&D projects. This second source helped to update the data base to 1977 and provide product safety-related R&D projects. Contact with SSIE personnel suggests that most government projects are included but that many industry-funded projects are omitted because firms did not report all their work for the SSIE file.

Appendix B provides a list of projects in the data base, covering the period 1973-77. The number of projects sponsored by various Federal agencies such as the Department of Transportation (DOT), Department of Defense (DOD), Federal Energy Administration (FEA), Environmental Protection Agency (EPA), etc. is used as a surrogate for government support for automotive-related R&D. From descriptions provided or from the abstract of each research project, classifications were made in respect to: the technology addressed, sponsoring organization, performing organization, cost, and in respect to the type and technical focus of the work.

a. Type of research was broken down into five categories:

-survey work
-basic research
-applied research
-development or
-support of Federal rulemaking.

b. The focus of the research was represented by three major categories:

-fuel economy (including advanced fuels and engines)
-pollution control
-product safety

c. The institutional structure concerns the type of organizations that sponsored and performed the research:

-government agency
-major automobile firm
-automobile supplier
-other industrial firm
-university or consulting firm

3.1.1 Types of R&D Projects

Some projects have multiple foci. Table 3.1 shows the nature of Federal support by type and focus of project in each of the three major areas of interest. Unfortunately, the data on safety projects may not be representative of all Federal projects because the basic source data did not offer comprehensive coverage of R&D projects in this category.

Table 3.1

TYPE AND FOCUS OF FEDERAL R & D PROJECTS

Type of Research	Number of projects sponsored by Federal agencies for:							
	Fuel economy		Pollution control		Product safety		Total	
	No.	%	No.	%	No.	%	No.	%
Survey research	12	14	4	6.5	8	18	24	12.5
Basic research	8	9	11	18.0	3	7	22	11.5
Applied research	35	41	25	40.0	2	5	62	32.0
Developmental research	14	16	9	14.5	1	2	24	12.5
Research to support Fed. rulemaking	17	20	13	21.0	30	68	60	31.5
Total	86	100	62	100.0	44	100	192	100.0

The above table shows that 44 percent of all Federally-sponsored projects have not undertaken the type of work that promises to advance technology directly. Thirty-one percent of the projects supported Federal regulatory efforts and the other twelve percent were for surveys of various types. The government has invested heavily in applied research (32 percent of all projects), virtually neglecting basic research. In terms of dollars, the emphasis is even more biased toward applied research since applied projects tend to be more expensive than basic research. In the area of safety, there seems to be a very strong emphasis on R&D to support regulatory action, as opposed to work that might more directly support innovation.

Of the government agencies supporting research, it is mainly the National Science Foundation, in its traditional role, that shows an interest in basic research. The major thrust of research and development by DOT has been to either sponsor R&D to back regulation or to undertake development work, most frequently to improve existing technology. Table 3.2 shows the distribution of projects by agency.

Table 3.2

TYPE OF FEDERAL R & D PROJECT BY AGENCY

Type of Research	Number of projects sponsored by Federal agencies			
	DOT	DOD	NSF	Others
Survey	13	-	2	9
Basic	4	-	16	2
Applied	18	11	5	28
Development	8	8	1	7
Regulatory support	44	-	5	11
Total	87	19	29	57

The vast majority of R&D projects have sought improvements based on technologies that are either currently in mass production or that rely on well-established concepts. A general idea of the project breakdown by the type of technology is provided in Table 3.3 below. While errors may have been introduced in classifying the projects in this way we are under the impression that the underlying distribution would not be far from the one suggested in this table.

Table 3.3

TYPE OF TECHNOLOGY UNDERLYING R&D PROJECT*

		Projects with Fuel Economy Focus (%)	Projects with Emission Improvement Focus (%)
1.	Improvements for current technology	61.0	72.1
2.	Incremental advances based on current technologies	4.3	4.9
3.	Different combustion technologies		
	a) External combustion	2.4	5.8
	b) Rotary engine	1.8	1.6
	c) Turbine	4.9	7.4
4.	Electric vehicle and related technology	11.0	4.1
5.	Fuel research	13.4	4.1
6.	Weight reduction by material substitution	1.2	____
	Total	100.0%	100.0%

*Based on analysis of projects in sample

Over eighty percent of the projects supported by both NSF and DOT sought advances related to conventional technologies, in both categories above. Other government organizations, notably DOD, ERDA and EPA, sponsored a larger percentage of projects concerned with unconventional technologies. The automobile manufacturers and automobile supplier firms seem to have supported a larger percentage of projects related to unconventional technologies. A note of caution is appropriate here, for the data would suggest that most firms in the automotive industry do not seem to have reported many of their internal projects.

3.1.2 Resource Commitments

On the average the reported spending per project by the Federal agencies projects has been appropriate for surveys, legislative support and other analytical work but quite modest for significant technological development.

Table 3.4 shows a comparison of the average project size in dollar terms.

TABLE 3.4 AVERAGE R&D FUNDING FOR A PROJECT ($ in 000)

Federal Agency	On fuel economy	On pollution control
DOT	349	247
DOD	571	498
NSF	117	77
Others	604	425

These data on project expenditure levels should be interpreted as sample statistics since data on funding levels were not available for nearly half of the R&D projects reported in the data base. The probable bias induced by the missing data causes average funding levels to be overstated. It is more likely that cost figures have been omitted for smaller projects. This reinforces the idea that arises from the prior tables -- that the overall pattern is one that embraces a number of small projects as opposed to fewer big ones. The emphasis in those projects which have been funded seems to favor modest improvements in existing technology, survey research and regulatory support, over the more expensive ground-breaking work that is required to bring new concepts near the realm of practice. Table 3.5 provides further evidence bearing on the level of resource commitments.

TABLE 3.5 PERCENT OF FEDERAL PROJECTS BY FUNDING LEVEL

R&D Expenses Category (in $1000)	Fuel economy				Pollution control			
	DOT	DOD	NSF	Other Fed.	DOT	DOD	NSF	Other Fed.
< 20	48.4	10.0	5.9	42.9	50.0	20.0	21.4	37.0
20-150	32.3	20.0	76.5	17.9	21.4	20.0	64.3	25.9
150-1000	16.1	60.0	17.6	28.6	21.4	50.0	14.3	29.6
> 1000	3.2	10.0	-	10.7	7.1	10.0	-	7.4

Over 95% of all projects sponsored by various Federal agencies on fuel economy, pollution control, and safety represent projects of less than a million dollars each. Only 9 projects in all in our data base of 192 Federally sponsored projects were supported at levels over one million dollars. Not much in the way of serious development work can be done with such modest resource investments. Around fifty percent of all Department of Transportation-sponsored projects were funded at levels under $20,000 per project.

3.1.3 Institutional Structure

Finally there is the question of the institutional context in which the projects are sponsored and conducted. The sample data on which our analysis is based point to a conclusion that the bulk of the Federal government's support for R&D projects has been to universities, research organizations, industry associations or other organizations that are not in the mainstream of the automobile industry. Table 3.6 is a matrix showing the sponsor and performer of R&D in the auto industry, that has been derived from the present sample of projects.

Table 3.6

AUTO INDUSTRY R&D

SPONSOR-PERFORMER MATRIX

	NUMBER OF PROJECTS SPONSORED/PERFORMED IN THE PERIOD 1973-77					
Sponsor / Performer	DOT	Other Federal & State Government Agencies	Auto Manufacturers	Suppliers to the Auto Industry	Universities, Industry Assoc. & Others	Total
DOT	3	2	0	0	0	5
Other Federal & State Govt. agencies	14	31	0	0	0	45
Auto manufacturers	3	4	26	0	0	33
Suppliers to the auto industry	2	12	3	70	1	88
Universities, Industry Ass. & others	64	63	4	1	30	162
Total	86	112	33	71	31	333

It is clear from Table 3.6 that the Federal sponsorship of auto R&D has not often included organizations within the industry, whether they be manufacturers or suppliers. While the data base does suffer from incomplete information on the projects sponsored and performed by the auto manufacturers and suppliers, we believe it is accurate to state that projects which received Federal assistance would all have been reported; and the unreported ones are largely self-sponsored. So the incompleteness of data does not detract from the conclusion that by and large the Federal sponsors in general, and DOT in particular, have not involved the auto industry in Federal R&D activities.

To the extent that Federal R&D programs intend to stimulate technological change in future cars, failure to involve major production firms in this process is of serious concern. The problems of successful technology transfer to mass production industries probably loom larger than those which arise in carrying out laboratory-oriented research work in the first place. Lessons from the aircraft and electronics industry, as represented earlier, suggest that innovative component developers must be intimately engaged in the process of successful system innovations. The whole question of appropriate institutional involvement in the conduct of R&D is a question worthy of close examination if the role of Federal R&D is to be considered.

A revealing difference among R&D funding patterns of three important agencies (DOT, DOD, and NSF) is suggested by the earlier table (Table 3.5). It is fair to say that the Department of Defense, despite the sporadic criticism it receives, probably has the longest history and the most extensive experience in successfully reducing technological concepts to practice, under both routine and crisis conditions. Although it is not principally concerned with regulatory issues, it is an agency whose R&D programs must be responsive to the needs of a large operational capability; and in this sense its mission may be somewhat comparable with DOT's. Would the Department of Defense's relative emphasis on larger projects and on applied R&D be appropriate to bring new concepts to practice? The NSF on the other hand has a mission to support more fundamental research in the disciplines. It has a distinguished history of supporting important work underlying many innovations. It is not surprising that NSF tends to fund many projects at lower levels of funding while DOD seems to focus its efforts directly on larger projects, taking them closer to practice than does DOT.

The Department of Transportation's posture may be very appropriate under the assumption that large firms with large R&D expenditures can do much of their own work. The DOT's R&D sponsorship pattern may well reflect this rationale. At the same time the currently intense pressure of product regulation to bring about change in present vehicles requires the industry to divert most of its R&D for very short-run goals involving minor improvements. Compared to other areas the levels of R&D funding by the Federal government in serious automotive development projects is quite small. It would be unfortunate if the appearance of large industry budgets for R&D were allowed to shape the effectiveness of Federal expenditures programs unduly when significant societal benefits are at stake. It would seem that serious attention needs to be called to the entire Federal R&D programs posture to insure that the "tail is not wagging the dog," as it were.

3.1.4 Summary

It is difficult to sum up concisely the full range of Federal programs in relation to the framework that was previously proposed, but some central tendencies are apparent. Few of the Federal R&D programs seem to have envisioned strong technology push, in the sense that this is apparent in other industries. It would seem that energy-related efforts have perhaps been taken slightly more seriously in this respect, based purely on the statistical evidence. The pattern of R&D investment does not seem sufficiently focused in terms of resources committed, institutional context or technological objectives to bring forth fundamentally new technological concepts of automotive transportation which the U.S. may need in the 1990s and beyond. Coming at a time when the industry's resources are also diverted to immediate regulatory requirements this issue looms as an important national problem. All in all, it would be judged that the degree of technology push is very weak to moderately weak, depending on the area.

3.2 Product Intervention and Market Modification - The Technology Pull Option

Federal intervention in the automobile industry has an earlier origin than is frequently recognized, predating the heated controversy of the 1960s. Until a definitive history on the subject is written the full extent of early involvement will remain clouded. That such interventions occurred, however, is documented by Nevins[(23)] in his account of one incident at Ford around 1924, in which "Cast Iron Charlie" Sorensen, a principal architect of Henry Ford's product and production policy, acquiesced to government pressure that four wheel brakes be made standard on Ford cars so that accidents would be reduced.

3.2.1 Pollution Control

The current era of intense Federal involvement, however, had its origin in the 1950s with research on sources of air pollution in California. From this genesis the present pattern of Federal action has evolved in different areas, shaped in its own course by the strong sequence of action and response by the automobile industry, the government, and other interests. While there are significant differences among the major areas of pollution control, safety and fuel economy, pertinent to issues of interest in this report, the similarities are probably more important. Much of the writing on the subject has sought to assign responsibility for problems along the sequence of events to either the industry or the government. This underlying theme is apparent in the Goodson and Bunch reports cited earlier. The present purpose, however, is to summarize the position that has been reached, in terms of the present framework.

According to Jacoby and Steinbruner's account, the link among air pollution, "smog," the automobile, and health hazards, was established in

1950 by research at the California Institute of Technology. This criterion or needs research, in terms of present concepts, ultimately stimulated or enabled public concern to focus on automobile pollution as a major problem. As more public concern was expressed over the issue and interest broadened, the automobile industry introduced the first in a sequence of corrective devices, the "positive crankcase ventilation" device. It was installed on cars sold in California as of the 1961 model year and subsequently the automobile companies voluntarily equipped all cars sold in the U.S. with this device as of the 1963 model year. California passed legislation requiring exhaust control devices either as original installed equipment by the manufacturer (OEM) or by "aftermarket" suppliers, approving four suppliers' devices for the 1966 model year. The major U.S. automobile producers responded to this invitation for competitive intrusion of suppliers by installing exhaust devices on California cars for the 1966 model year.[24]

Federal legislation in the area came in 1955 (PL 84-159) and supported research on pollution effects but it did not provide enforcement. The 1963 Roberts bill (PL 88-515) undertook the first Federal action, that would be considered market modification in the present framework. The General Services Administration was directed to set standards for the purchase of automobiles by the government. The seventeen standards subsequently issued pertained mostly to safety but they also included an exhaust emission control system. They were required for government purchases as of the 1967 model year but the U.S. automobile firms incorporated fifteen of these as standard on all U.S. cars for the 1966 model year and announced plans to incorporate the remaining three by the 1967 or 1968 model year.

Lawrence White[25] described the situation in the automobile industry at this time in the following terms : "Having shown 'good faith' by making most of the GSA items standard on their 1966 cars and announcing their attention to make the rest standard – the U.S. companies could have avoided the imposition of Federal standards for all cars. But then a minor scandal broke over the Corvair, Ralph Nader and General Motors." The Motor Vehicle Air Pollution Control Act was passed in 1965 (PL 89-272), establishing the principle of technological standards for pollution control. Pressure for tighter standards continued to mount, becoming an issue in the political campaigns of the presidential contenders in 1972. A chronology of legislation and selected standard setting which followed is provided in Appendix A, as mentioned earlier, and a more completely developed history is available in several published sources.

These actions set the pattern and subsequent moves have followed in the same context: In 1970 procedures for measurement were added; oxides of nitrogen standards were added to the previous hydrocarbons and carbon monoxide standards, more stringent levels were set and effective dates were tightened. The Environmental Protection Agency was formed to administer the regulations late in 1970. In total Goodson[26] documents fifty-eight subsequent transactions from 1970 until mid-1976 involving further legislative or administrative action to revise or tighten standards, change effective dates, specify required maintenance of equipment installed on vehicles and the useful life of the controls, etc.

The pattern of Federal action in this sequence is rather clear. It began with persuasion and the use of government procurement to induce change. These are technology pull measures in the present frame of reference. Few would question that the automobile firms were initially reluctant to introduce changes that were not drawn in by traditional competitive means, but even so progress was made through these weaker government actions.

Impatience with the lead times for changes led to the replacement of these market modification actions by government intervention which took the form of technologically based standards. Once established as the mandate of a Federal agency, subsequent action has reinforced this mode of Federal control.

Broader actions that might have evoked the competitive nature of the automobile firms are missing in this rather narrow range of actions. The potential for different approaches is suggested by Lawrence White.[27] "Is the current system of controls the most efficient or the most equitable method of achieving these benefits? Here the answer is not as clear. From a legislative standpoint the auto companies were the easiest target for remedial action on pollution. 'It is their product that is directly causing the pollution; let them clean it up,' seemed to be the general attitude. The possibility of more stringent state inspections and maintenance requirements as an alternative or supplement to other measures were not considered. The states were not eager to incur the extra costs of vehicle inspection. A more complete approach to the automobile pollution problem is possible. Standards, prohibitions, fines and differential taxes would be ways to achieve a given level of control (presumably leveled at the consumer)."

Since White wrote his book some other efforts to affect automotive pollution have been undertaken at the user level. All in all, however, reliance on control has rested singularly with regulatory intervention in respect to the product itself.

3.2.2 Safety Interventions

In respect to safety the overall pattern of Federal action within the present technology pull category has not been materially different than for pollution control. From early actions connected to pollution that relied on persuasion and the use of government procurement as stimuli, heavy reliance came to be placed on regulatory standards. There has probably been a broader approach to safety than pollution control with related government programs to achieve better emergency medical services, improved highway design and traffic control and improved information for consumers, among others.

The opportunity to incorporate incentives for safety more directly into the competitive system is probably much richer in respect to safety, however, than in respect to pollution. Quoting again from White[28] on this point he notes: "The logical candidate for this role would have been the insurance companies. Collision and medical insurance, were sizable enough to warrant insurance company interest in safety. A competitive industry might have offered differential rates according to the safety features of different cars or of particular features. Liability insurance should have been cheaper if one had a dual brake system or nonglare surfaces on one's car." Of course since White wrote this the insurance companies have taken a more active role in safety and collision repair cost issues. The curious fact is that this rich opportunity was not utilized earlier as a systematic component of government actions.

The same point can be made in respect to other opportunities such as improved safety information for the consumer and, as Bunch notes, better research on safety problems. As with pollution control the principal mode of government action has relied upon government intervention with the producer in respect to product characteristics. There is good reason to believe that effective technological progress on safety would have been greatly facilitated had the competitive mechanisms of the automobile industry been engaged in the problem.

3.2.3 Fuel Economy Interventions

The picture on fuel economy is somewhat different than either pollution control or safety. The potential danger of gasoline shortages was brought to the entire nation's attention through the external threat of the 1973 oil embargo in the Mid-East. For a time drivers were threatened with the loss of vital transportation services by lack of gasoline. Early Federal action again took the form of persuasion as President Ford sought voluntary cooperation of producers in improving fuel economy.

In addition improved information was provided consumers about fuel economy through EPA ratings--thereby raising this aspect of vehicle performance to greater prominence, as a competitive variable. The short-lived rise in small car sales during the embargo vividly pointed out the potential importance of fuel scarcity to the automobile firms.

Fuel economy had always been a competitive variable, even if minor for most market segments. The whole introduction of the problem on the national scene acted to involve competitive mechanisms much more strongly than for safety or certainly for the pollution arena.

The early stage of Federal involvement was followed by Federal intervention to alter product characteristics, as in the other cases. This time there were differences. The 1975 law establishing the requirement that producers achieve a 27.5 miles per gallon fleet-weighted standard by 1985 (PL 94-163) carried penalties with implications for profit and the relative market share position of the major producers. For example, with a predominant position in the large car market, General Motors would lose market share if production of these larger cars had to be given up. Conversely, Ford and Chrysler might gain or vice versa. While the legislation would seem to be largely a performance standard, in effect it has competitive implications and may also be considered a market modification action.

To the extent that different responses would be expected between product intervention and market modification actions, they should be apparent in different outcomes of fuel economy regulation and the other two areas.

3.3 Summary of Government Initiatives

Definite patterns of technology pull actions by the government within the technology push and pull options are apparent in the historical sequence of events. The overall pattern is one of increasing government intervention in product characteristics. In terms of market modification, the Federal Government has made very weak attempts to achieve objectives through changes in market mechanisms. Some major actions it could have taken to influence change through market mechanisms are:

a. Levy a higher tax on gasoline, thus making fuel economy of direct concern to the consumer.

b. Enforce stricter motor vehicle inspection, and levy fines on cars polluting in excess of Federal standards.

c. Enforce safety standards, by making their neglect a traffic offense.

d. Involve competitive mechanisms more directly in safety through the use of differential insurance rates for important safety innovations.

Such actions might have created direct consumer pull for product improvement. The effect of product performance regulation in the areas of safety, pollution control and fuel economy has been to induce intense technology pull incentives for short-range technological solutions. The strongest incentives in this respect have come from recent fuel economy regulation where regulatory requirements also engage competitive mechanisms so that competitive and regulatory incentives are joined in a very real sense. Federal initiatives in respect to direct technology push options have been weak. This effect has been amplified because more and more of the industry's resources have been diverted into shorter-range technological programs.

The following chapter will consider actual patterns of improvement in automotive performance characteristics in response to these Federal initiatives.

4. The Effect of Federal Initiatives on Automotive Performance

Government action and industry response in the areas of safety, pollution control and energy efficiency have changed the characteristics of US automobiles significantly. Perhaps the most important point is that significant change has come about, and in a way that has not yet significantly raised the price of automobiles to the American consumer. This is not a trite comment. In relation to the achievements of government intervention in other fields like nuclear power, coal, housing, health care delivery, etc., the outcome has been quite successful to date. Credit is due to the hard work of those in both industry and government, who have worked out solutions despite differences of opinion. The purpose of this section is to briefly review the nature of change in each area, but without regard to costs involved.

4.1 Emission Control

Emission levels for selected years are presented in Table 4.1 which follows. The degree of change in emissions is suggested by data which Goodson presents in his recent report as cited earlier. Although these data were apparently developed to illustrate the industry's delay in responding to regulatory goals the data usefully summarize the profile of change as well.

Appendix C, reproduced from Goodson's report, illustrates the build-up in regulatory standards for automobile emissions and the corresponding performance of new cars from 1967 until 1976 in respect to these standards. The light outer lines profile the change in proposed or required standards for hydrocarbons, carbon monoxide, and oxides of nitrogen. Each higher vertical level represents a more stringent requirement. The sloping sections of light lines generally connect the time periods when the requirement was set or proposed with the time periods when they were to go into effect. The shaded area indicates delay in the scheduled date for implementing the standard, and the heavy line shows the profile on which these capabilities were implemented in new car production. The shaded area highlights periods and magnitudes of postponed requirements.

The data in Appendix C show a step-by-step improvements in emission levels of new model cars in response to regulatory standards as opposed to a continuing trend of improvement. Table 4.1 helps to explain the trends in Appendix C by noting the particular levels of hydrocarbons, carbon monoxide and oxides of nitrogen produced by new cars in 1968, 1972 and 1976.

Table 4.1

EMISSION LEVELS ACHIEVED BY THE INDUSTRY FOR NEW CARS

(gms/mile for standardized driving cycle)

	HC	CO	NO_x
1968	7.2	72	-
1972	3.4	39	-
1976	1.5	15	3.1
Standards			
1977	1.5	15	2.0
1978	0.41	3.4	0.4

Data showing emission characteristics of on-the-road vehicles were also analyzed. These data were obtained from the State of New Jersey, who compiled them from stationary tests conducted as part of a vehicle inspection program during the month of August 1976. The data yielded the following trends in hydrocarbon and carbon monoxide emissions.

Table 4.2

AVERAGE HYDROCARBON EMISSIONS IN PPM OF ON-THE-ROAD VEHICLES

Model Year	Mileage run <40,000 miles	Mileage run 40-60,000 miles	Mileage run >60,000 miles
1962-64	-	-	701
1965-67	-	651	653
1968-69	446	384	474
1970-71	231	271	416
1972-73	202	168	317
1974-75	170	249	-
1976	90	-	-

Notes: 1. Cells having less than 10 observations have been excluded.
2. 100 ppm of HC is equivalent to 2.62 gms/mile by the new test procedure.

Only data on hydrocarbon emissions trends are given in Table 4.2, but trends in carbon monoxide emissions are quite similar. The trends in emission of new vehicles (less than 40,000 miles) confirm the gains that are predicted by factory inspections on which Appendix C is based. The percentage improvement in the emissions of new vehicles in use from 1968 to 1976 slightly exceeds the percentage improvement based on factory test data. The trends in high use vehicles predict a potential problem in maintenance or enforcement for on-the-road vehicles for the same improvement is not apparent for high use vehicles.

The important message contained in these tables is that significant progress can and has been realized in controlling emissions. The nature of the progress is of particular interest, however. Commenting on the industry's response Goodson[(29)] observes, "The proposed or required emissions have always been more stringent than emission standards actually implemented in new cars." What Goodson describes might be characterized as satisficing behavior.

Improvements as shown in Figure 4.1 have come in steps or stages to meet more stringent requirements. Improvements have not taken the form of spontaneous voluntary advances or of a continuous trend toward lower emissions that is often found in product attributes that are competitively important.

The setting of emission levels is an issue of continuing controversy. According to industry statements, technology is not available to improve emission levels further without relinquishing the planned improvement in fuel economy, for vehicle sizes and costs that are now attractive to the US buyer.

As if to demonstrate the genuineness of their claim, GM and Ford both took the position that they would have to shut down their factories to avoid breaking the law by producing cars that did meet Federal standards for 1978. It seems reasonable to conclude that there is a genuine lack of technology that is cost effective for large cars that accounts for delays in progress on emission performance. It is clear that the present set of Federal initiatives and industry action have failed to achieve the breakthroughs that were envisioned by legislation in respect to emission improvements. One must also notice the striking absence of market modification actions, and effective Federal technology push initiatives in the area of pollution control.

4.2 Safety

The nature of Federal regulations and industry response in the area of safety in characterized in a second exhibit from Goodson's study, included here as Appendix D. This exhibit concerns changes in Occupant Crash Protection in New Passenger Cars and it is presented in a format similar to the prior exhibit on Emissions. The light outer lines represent the envelope of proposed or enacted standards, while the heavy lines indicate the standards achieved in new cars within various years. The shaded areas indicate delay in implementing legislated standards, as originally scheduled.

In characterizing the nature of industry's progress in this area Goodson[30] finds: "Again, as in the case of emission standards, there have been significant delays, and the proposed levels for occupant restraint systems have not been realized in the motor vehicle fleet." In the case of safety, however, the issue is not nearly so neat as with emissions. It is not clear that industry response is captured so simply. On one hand Bunch questions such sweeping statements about industry resistance to improved safety. His research shows underlying industry support for safety standards in the early years, in instances where standards were thoroughly analyzed by the government and lead times were adequate. In fact, he observes that the industry seems to be able to accomplish anything if lead times are long enough. Response to a particular type of standard does not mean that improvement is not being achieved in other respects. Lawrence White's analysis[31] of the industry's performance in regard to safety suggests a somewhat different pattern than emissions. "The net effect of the legislation and the National Highway Safety Bureau has been positive. Not only have the standards gone into effect but the companies have been spurred to develop safety features on their own. Ford in its 1968 model cars introduced an energy-absorbing frame; General Motors in its 1969 cars introduced special side reinforcements to reduce the penetration of a vehicle by another vehicle hitting it from the side. Ford also introduced a skid-control braking device on some 1969 models. Safety is no longer an unmentionable word in the automobile industry."

The thrust of White's argument is that in safety the various initiatives have caused some market modification effects to be realized in the sense of our framework. There is evidence that safety improvement is now more frequently stimulated by competitive action, as can be seen from the use of safety features to differentiate products in automobile advertisements. There has clearly been disagreement over appropriate standards. The recent air-bag controversy is a case in point. Congressional action to remove ignition, and seat belt interlock features, suggests that there is far from complete consensus, even in the government, about appropriate safety requirements. As in the air-bag issue, disagreement is sharpest where there are substantial reasons for doubt on both sides of the issue. On balance it would seem that important safety improvements have been realized and they have risen from competitive responses within the industry to a much greater extent than in the emissions area.

4.3 Fuel Economy

In an interesting paper written five years ago, Austin and Hellman[32] document the trends and make predictions about sales-weighted fuel economy. (See Appendix E) This projection helps to put recent achievements in perspective. The sales-weighted fuel economy for a given model year is measured in miles per gallon, and given by the formula:

$$\text{sales-weighted mpg} = \frac{235.2}{(f_i c_i)}$$

where f_i = fraction of total sales for a given model year which occurred in inertia weight class i,

c_i = fuel consumption in litre/100 km in inertia weight class i for a given model year, and

235.2 = conversion constant used to convert metric to English units.

The trends in Appendix E project the picture in fuel economy that was unfolding before the 1973 Mid-East oil crisis. There was a steady degradation in fuel economy, and a sales-weighted fuel economy of little over 11.5 mpg was forecast for 1973. The authors go on to demonstrate how sales-weighted fuel economy was influenced by stricter emission control legislation. They hypothesize "More emission control is required for heavier vehicles, on the basis of grams of pollutants allowable per gram of fuel burned. In general, uncontrolled NO_x emissions are proportional to vehicle weight, lighter vehicles requiring less NO_x control than heavier vehicles. The current techniques for NO_x control chosen by the manufacturers of heavier vehicles are those which cause fuel economy penalties." While they attribute some fuel saving to the higher air-fuel ratio used by manufacturers to reduce HC and CO emission, the savings have been more than offset by the excess fuel consumed on account of the pollution control devices. With a clear trend towards tightening emission control legislation in the future, the forecasts as of 1973 were gloomy for any improvement in fuel economy. The gradual but steady decline in sales-weighted fuel utilization seemed inevitable.

But then in 1973 the oil embargo hit the US. The future of gas supplies seemed in doubt and prices of gas went up sharply. Overnight there was concern over fuel economy among consumers. In late 1974, the Federal Government sought voluntary cooperation from the auto companies to achieve 40 percent improvement in gas mileage. In 1975, the FTC put together an "interim guideline" requiring that all advertisements with fuel economy claims carry EPA city and highway test results. Fuel economy seemed to have gathered increasing awareness. Under the combined effort of these market forces and government persuasion, the auto industry responded rapidly. Fuel economy improved dramatically in 1975 registering nearly two mpg jump in fleet-weighted fuel economy performance. Table 4.3 shows the dramatic improvement in 1975 and subsequent improvements in 1976 and 1977.

When considering the forces that induced these improvements, it is important to note that the Energy Policy and Conservation Act (PL 94-163) was passed in December 1975, but it did not set any standards for average fuel economy until 1978. It might also be noted that since the legislation was passed at the very end of 1975 it would not have influenced the initial improvements. The improvements in fuel economy since 1975 may therefore be credited to the efforts of the auto industry, not in response to Federal regulation but, perhaps, in response to market forces and in anticipation of regulatory requirements.

Table 43

DOMESTIC FLEET-WEIGHTED, FUEL ECONOMY (EPA COMPOSITE)

FOR MODEL YEARS 1961 ONWARD

Model Year	Fuel Economy mpg[a]	Fuel Economy mpg[b]
1961	15.0	13.6
2	15.0	14.0
3	15.0	12.6
4	15.0	13.5
1965	15.0	13.0
6	14.9	13.0
7	14.9	12.9
8	14.3	12.5
9	14.1	12.3
1970	14.1	12.5
1	13.7	12.3
2	13.5	12.0
3	13.0	11.5
4	12.9	
1975	14.8	
6	16.9	
7	17.8	
Federal Standards		
8	18.0	
9	19.0	
1980	20.0	

[a]Based on data from EPA data for yearly new US fleets, after adjustment for imports for production vehicles 1961-1977. Data and Analysis for 1981-84 Passenger Automobile Fuel Economy Standards: Summary Report, NHTSA, US Department of Transportation, February 28, 1977.

[b]The fuel economy figures reported in the two columns are different. The first column represents EPA data obtained from static dynamometer tests. The second column represents calculated fuel efficiencies based on DOT fleet fuel consumption data, which is an estimate of actual fuel consumption. The EPA data is approximately 14 percent higher than the DOT data due to systematic biases.

4.4 Summary

The patterns of progress in the three different areas of automotive performance differ from one another in important respects. These differences are intimately related to the form of Federal initiatives in these areas. Significant progress has been realized in all three areas but there are conspicuous differences in degree and in the promise for continuing future improvement that will be achieved without the spur of further Federal incentives.

At one extreme is the profile of change in emission control. Progress in this area has the quality of satisficing behavior in problem solving by the major producers. Requirements are met but not exceeded. Fuel economy improvements lie at the other extreme. The steep and steady trends of improvements since 1973 reflect optimizing behavior in problem solving or innovation by the automobile industry. The greatest rate of possible improvement is sought. Progress has preceded and exceeded Federal regulatory standards to date. Safety improvement would seem to lie in the middle ranges. Systematic progress has been realized but without the vigor that is apparent in fuel economy.

The link between the Federal initiatives and the extent of progress in the three areas would seem to be close. The automobile industry has traditionally responded with vigor to market pressures [33]. While emission initiatives have not been linked to market incentives or competitive mechanisms, fuel economy measures are! The combination of stringent product performance regulation and the linkages to competitive factors have created an intensely powerful force for rapid technological change. A very real danger is that the incentive for immediate progress is so intense that longer run options will not be pursued.

5. Conclusions

The need for action is succintly stated by Carroll Wilson[34] in a report on alternative federal energy strategies: "Unless appropriate remedies are applied soon, the demand for petroleum in the non-Communist world will probably overtake supplies around 1985 to 1995. That is the maximum time we have: thirteen years, give or take five. It might be less. Petroleum demand could exceed supply as early as 1983 if the OPEC countries maintain their present production ceilings bec[illegible]se oil in the ground is more valuable to them than extra dollars they cannot use. We do not have much time to learn how to replace or decrease our dependence on the fuel that for three decades has fed the expansion of Western living standards and the hopes of all nations for material betterment. Time is our most precious resource. It must be used as wisely as energy."

Federal initiatives in the auto industry have to be viewed in this broader context of a projected liquid fuel crisis within the next decade. The present state of the art in the automotive technology poses serious trade-off dilemmas for government policy. Pollution control devices presently in use seem to have adverse effects on fuel economy. Likewise, downsizing, a popular option to reduce fleet-weighted fuel consumption, apparently has adverse effects on passenger safety. Currently available technology appears to be strained in simultaneously addressing the three issues of pollution control, improved fuel economy and improved passenger safety, at product prices that will avoid national economic disruption. The predicted liquid fuel crisis will certainly press the limitations of current technology. Yet current Federal energy policy seems to have placed infinite faith in the innovative resources of firms within the transportation industry in general, and the automobile industry in particular, predicting[35] "an absolute reduction in gasoline use, from 4.5 Million Barrels per Day of Oil Equivalent (MBDOE) in 1972 to 3.8 MBDOE in 2000, due to improvements in fuel economy, and increased use of diesel engines." If the risk in national energy policy is to be reduced to reasonable levels then wishful thinking has to be translated into reality, major technological innovations are needed -- and needed within present planning horizons. Since the Federal Government has implicitly assumed major responsibility over the last decade for progress in the auto industry, there is a serious national risk if the wrong initiatives are assumed for future transportation plans.

The Federal Task Force's Report[36] on Motor Vehicle Goals beyond 1980 identifies auto concepts that are needed for the future. Table 5.1 is a list of concepts, including their projected impact on fuel economy. As can be seen from the table, the rapid rate of improvement that is so apparent in recent trends can be sustained for a few more years without significantly different technology, through weight-conscious and upgraded designs and the use of diesel engines. To go beyond this major innovation is required, however, involving innovative structure, advanced engine and upgraded drivetrain -- in short, a completely new automobile. Judged against such an assessment of what a preferred concept for auto design should be, the plans for realizing it seem to place undue faith in a Technology Pull Option. They seem based on the hope that with stringent enough fuel economy regulation the automobile industry will somehow come up with a new technological solution.

Table 5.1

FLEET AVERAGED FUEL ECONOMY (EPA COMPOSITE MPG OF GASOLINE EQUIVALENT) FOR TEN SELECTED TECHNOLOGY COMBINATIONS AT TWO PERFORMANCE AND THREE EMISSION LEVELS (SAFETY LEVEL I)

Configuration Number	Performance Hp/Wt	Technology			Composite mpg (Gasoline Equivalent) For 4, 5 and 6 Passenger Autos Safety Level I					
					Emissions Level I 1.5/15/3.1 (P=0)		Emissions Level II* 0.41/3.4/2.0 (P=0.06)		Emissions Level III* 0.41/3.4/0.4 (P=0.12)	
		Weight Configura.	Engine	Drivetrain	Low	High	Low	High	Low	High
1a	0.03	Current	Current	Current	17.1	17.1	15.7	15.7	14.3	14.3
1b	0.02	Current	Current	Current	21.1	21.1	19.5	19.5	17.8	17.8
2a	0.03	Wt. Cons.	Current	Current	21.2	19.5	19.9	18.1	18.5	16.8
2b	0.02	Wt. Cons.	Current	Current	25.9	23.8	24.3	22.1	22.8	20.6
3a	0.03	Wt. Cons.	Top '75	Current	24.2	22.4	22.7	20.8	21.2	19.3
3b	0.02	Wt. Cons.	Top '75	Current	29.5	27.2	27.8	25.4	26.0	23.6
4a	0.03	Wt. Cons.	Top '75	Upgraded	26.3	24.4	24.8	22.7	23.1	21.0
4b	0.02	Wt. Cons.	Top '75	Upgraded	31.0	28.6	29.2	26.7	27.3	24.7
5a	0.03	Innov.	Top '75	Upgraded	29.2	26.8	27.7	25.2	26.0	23.5
5b	0.02	Innov.	Top '75	Upgraded	34.1	31.1	32.3	29.3	30.5	27.4
6a	0.03	Wt. Cons.	Diesel	Current	28.4	26.7	28.4	26.7	Not Known	Not Known
6b	0.02	Wt. Cons.	Diesel	Current	34.0	31.8	34.0	31.8		
7a	0.03	Wt. Cons.	Diesel	Upgraded	31.0	29.1	31.0	29.1		
7b	0.02	Wt. Cons.	Diesel	Upgraded	35.7	33.5	35.7	33.5		
8a	0.03	Innov.	Diesel	Upgraded	33.6	31.4	33.6	31.4		
8b	0.02	Innov.	Diesel	Upgraded	38.6	35.9	38.6	35.9		
9a	0.03	Wt. Cons.	Adv.	Current	28.1	26.1	28.1	26.1	28.1	26.1
9b	0.02	Wt. Cons.	Adv.	Current	33.5	31.0	33.5	31.0	33.5	31.0
10a	0.03	Innov.	Adv.	Upgraded	33.6	31.0	33.6	31.0	33.6	31.0
10b	0.02	Innov.	Adv.	Upgraded	38.4	35.3	38.4	35.3	38.4	35.3

NOTE: Estimates of fuel economy penalties for future emissions standards vary from negligible to these values shown. (Reference 6)

Table 5-17 from the Report by The Federal Task Force on Motor Vehicle Goals beyond 1980 Vol. 1980, September 2, 1978, p. 5-25.

Even if the projected trend in automotive fuel economy can be sustained into the future as planned, however, is the planned reduction enough? Will an unanticipated increase in cars on the road here, or in other countries, cause a shortfall in the already optimistic demand/supply balance for petroleum? Given the potential world-wide petroleum scarcity in thirteen or so years, can the U.S. consumer, or the nation as a whole, afford to purchase oil without serious economic dislocation at the price that may be required to attract the projected quantities? There is a best-of-all-possible-worlds quality about many current plans.

As a matter of policy, action to develop innovative automobile technology would seem to deserve a high priority -- an innovative technology, offering a steep improvement in petroleum utilization rather that just an incremental advantage. The purpose of this report has been to review the characteristics of past Federal initiatives against the backdrop of such future national transportation needs. Several implications follow from this review as summarized in the subsequent paragraphs. The tentative nature of these recommendations should be recognized for in fact very little is known about the conditions that are needed to support and nurture major new innovations. The scope of the present review has been limited by the inadequate data sources on existing Federal R&D programs. It would be hoped that a comprehensive analysis could say that a stronger Federal initiative in R&D programs now exists. Unless a strong program can be documented, however, it would seem unwise to assume its existence.

The prospect for achieving the needed degree of innovation can be addressed within the framework of Chapter 2 as applied to review Federal initiative and their results in subsequent chapters. As Chapters 3 and 4 suggest, these initiatives have brought about change in respect to emissions, safety and fuel economy in a form that is consistent with the predictions of Chapter 2.

To summarize, Federal actions within the Direct Technology Push category have ranged from very modest to weak. R&D programs have generally focused on regulatory support, survey research, and developmental work that is funded at meager resource levels and that is centered around current technologies. The primary impetus for technological change has arisen from Federal regulations that have generated intense forces within the Indirect Technology Pull category. The effects are illustrated in Figure 5.1 below.

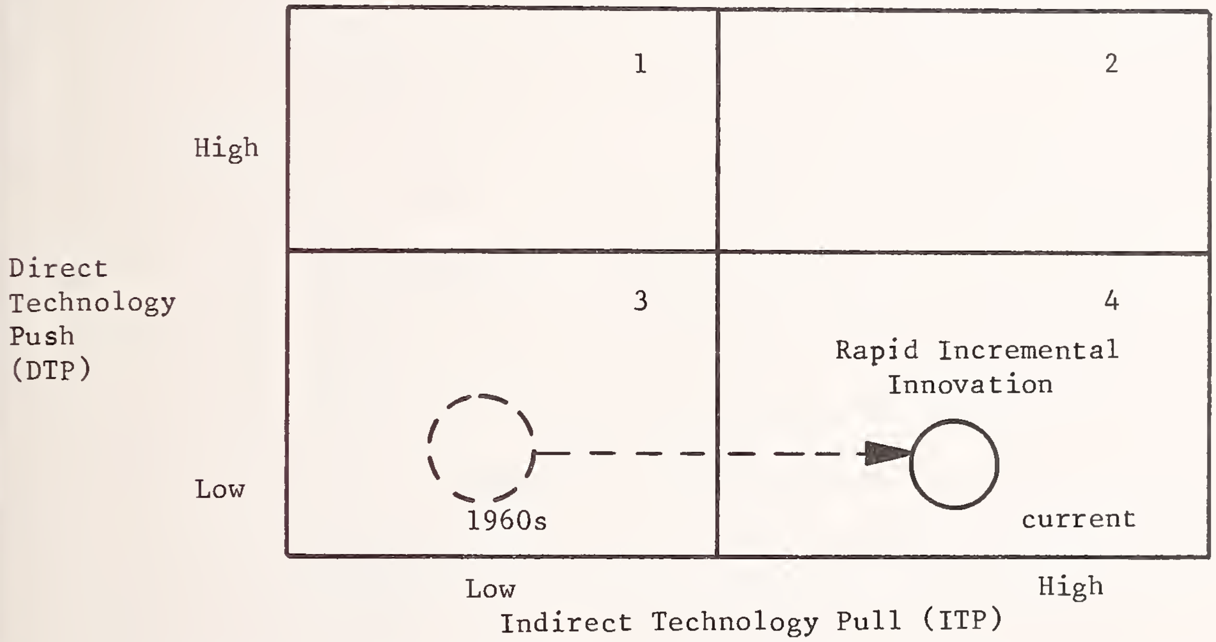

FIGURE 5.1 EFFECT OF FEDERAL INITIATIVES ON AUTOMOTIVE TECHNOLOGY

As a result of these forces, a steep and continuing trend has come about in fuel economy improvement, where ITP forces are the strongest. Progress has also been realized in safety and pollution but at a lesser rate, consistent with the nature and degree of ITP in these areas. Through these initiatives the rate of technological change has been substantially increased, but by means of incremental innovation based largely on improvements in existing technologies.

The outcome of prior Federal initiatives would seem to confirm the framework of Chapter 2. Progress has been induced by alterations in the environment (from Cell 3 to Cell 4 in Figure 5.1) but it is based on incremental rather than major innovation. There is reason to question seriously whether even more intense pressure will change this pattern, to call forth the major innovations that are needed.

The great danger is that future Federal policy regarding the automobile will continue the prior pattern of relying on technology pull, simply because it worked once. A recent speech by Joan Claybrook[37], administrator of NHSTA, is a harbinger of such an approach within DOT. In comments on the future technological challenge facing the automobile industry she noted: "there is a pressing agenda ahead, we should look forward as the horizon is etched with optimistic signs: Instead of crash survivability at 30 mph into a fixed barrier, protection should be available at 50 or 60 mph. Instead of 27.5 mph, it is not unrealistic to seek forty or fifty. ...it (the automobile industry) can use the most generous lead time now available to improve fuel economy and install air cushions, to do the right job and face up to its responsibilities to meet the challenge..."

The net consequences of further Federal initiatives within the present narrow pattern may be to entrench current technologies, foregoing important energy options that are promised by alternative technologies.

5.1 The Logic of Entrenchment

In the case of the automobile industry, there are at least five contributive causes that can lead to the entrenchment of technological progress. These are:

1) The industry is a mature industry, having perfected its present technology over the years to satisfy present market needs.

2) The tightening web of product regulations constrains choices of alternate technologies.

3) The present market incentives do not induce risk-taking behavior on the part of manufacturers beyond short-run regulatory requirements.

4) Government action in holding down gasoline prices shields the consumer from paying "a full and realistic cost for his fuel." This also eliminates market incentives that would spur technological change.

5) The government would not seem to have seriously engaged in creating new technologies of breakthrough importance for future national transportation needs.

Abernathy's study of innovation in the automobile industry[38] shows the historical growth of the automobile industry from what is termed a "fluid" toward a "specific" state. The latter stage is characterized by high productivity and a reduced potential for radical innovation. Unless the competitive environment is altered to favor a reverse transition towards more "fluid" states, the industry can be expected to face increasing problems in successfully undertaking major innovations.

These problems are aggravated by the growing and tightening web of product regulation that constrains choices of alternative technologies. As constraints on environmental impact and safety are tightened, the very nature of the regulatory process will cause them to be shaped, within limits of currently employed technologies. As this happens it becomes less and less likely that some other alternative technology can be successfully applied. For example, it is inconceivable that a coal-fired steam engine could ever again be employed in a car under current emission standards. Recent reports suggest that even some more promising current technologies are being questioned as their future health consequences are considered. As a case in point, there is now concern that diesel emissions may have carcinogenic effects on humans, although data are far from conclusive.

The effect of current incentives for the industry and the consumer are considered in a recent study of risks[39]. This study suggests that the present value surplus that will accrue to a customer under a given product modification option, and the marketing, financing, engineering and production risks to the manufacturer in pursuing that option, can be best reconciled under present market conditions only through incremental product changes. In other words, the risks and incentives facing a manufacturer do not encourage the customer to go in for an automobile using advanced technology which can initially be expected to cost more and has the risks of uncertain performance.

It is estimated that if the price of gasoline were not to be based on its present variable cost of production, but on the full cost of securing present supplies into the future, its economic price would be significantly higher. Although raising the price of gasoline as a means of reducing consumption may be politically untenable, the distortion this creates in incentives for new technology is also quite serious. A case in point is the electric vehicle, which has lain dormant since the turn of the century. The argument against it today is much the same as it was in 1900, viz,low operating speeds, high operating costs and restrictions on range of operations. While the electric vehicle may be reborn in the oil scarce era of the late 1990s, its development may have to be shelved until then; unless incentives comparable to increased gasoline prices are created.

Finally the absence of strong Federal support for R&D on major new technologies is seen as a major entrenching factor. The government has placed the responsibility for major R&D entirely on the shoulders of the industry. This comes at a time when the industry's resources are strained to the limit in conducting R&D to meet immediate regulatory requirements. We would predict that unless positive steps are taken further entrenchment can be expected and the prospects for major technological innovations that might obviate current limitations can be expected to remain dim.

5.2 Policy Options

The problem of choosing appropriate future policies in the automotive case, can be nicely depicted in terms of the present framework. If, as suggested the issue is one of encouraging major technological innovation, then it corresponds with a movement from Cell 4 to Cell 2 as illustrated in Figure 8. In practical terms this is equivalent to changing the conditions that support technological change within the industry from those that support accelerated incremental innovation to those that nurture major or radical innovation. This would not be necessary for total fleet production but rather for a segment of the industry large enough to support change effectively.

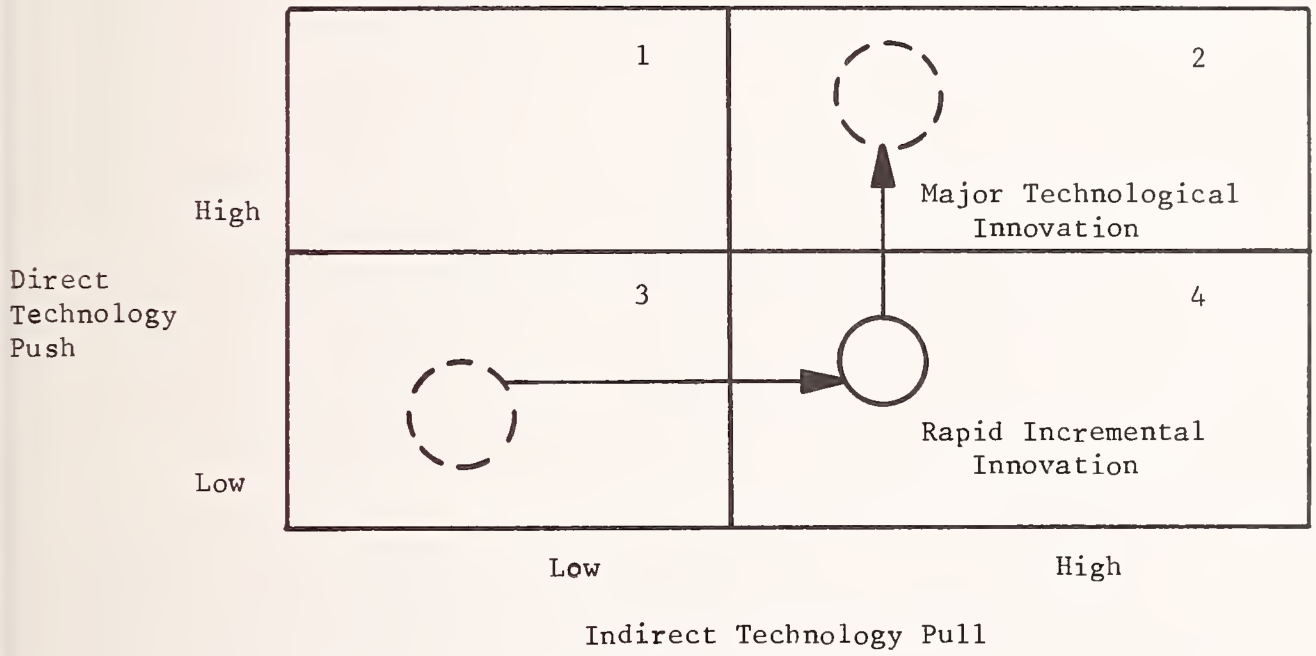

FIGURE 5.2 FUTURE POLICY OBJECTIVES

A change in the current patterns of Federal initiatives, regarding future automobile development, will be required to achieve these objectives. There is no one-best-way to create conditions that are sufficient to induce innovation but implications raised by the present analysis suggest several important steps toward such a goal. A fresh approach in both Federal R&D programs and special incentives is required.

a. Federal Commitment to Research and Development

A stronger Federal commitment to research and development results is needed. There are good reasons to question the old idea that "the industry can and should do it on their own." The necessary commitment will require the Federal organization, management and resources to support innovative concepts and bring advanced development programs much closer to practice than has been achieved in the past.

b. Creating an Appropriate Infrastructure for R&D

The problems which arise in coupling R&D programs to the solution of practical problems cannot be overemphasized. R&D programs should be conducted to capture the potential of innovative capabilities within the major automobile industry and important supply firms. Universities and independent research institutions have an important role to play but it is unrealistic to expect that new technology will be created and then transferred into practice. To promote effectiveness, firms with strong industrial capabilities should be engaged in the process of creating effective new technology to a greater extent than in the past.

c. Federal Incentives

Special incentives are needed to help nurture products that are derived from new technologies, in the early stages of their product life cycle. Federal procurement has played such a role successfully for many important innovations in other industries. Alternatively, special incentives could be created to stimulate market acceptance of innovative products.

Several attempts to create such incentives are evident in past Federal initiatives. The electric and hybrid vehicle procurement program is a recent example. A problem seems to have arisen, however, because these past programs have not been planned and integrated within the context of larger related R&D and production programs. The potential of such incentives as part of a larger program has therefore not really been properly tested. The use of incentives to stimulate innovation is an important option that remains untapped.

Actions to bring about the needed change will require both a stronger Federal commitment to R&D programs and positive steps in creating incentives that are appropriate for innovative products. The major purpose of the present report is to call attention to the need for a fresh approach.

REFERENCES

(1) R. E. Goodson, "Federal Regulation of Motor Vehicles," "A Summary of Actions Through Fuel Economy Legislation." - Purdue University, Lafayette IN, 1976.

(2) H. M. Bunch and M. Kubacki, "An Analysis of Industry Responses To Federal Regulations in Safety Requirements for New Automobiles." - University of Michigan, Ann Arbor MI, March 1977.

(3) J. B. Haywood, H. D. Jacoby and L. H. Linden, "The Role for Federal R&D on Alternative Automotive Power Systems," Massachusetts Institute of Technology, Energy Laboratory Report No. MIT-EL 74-103, 1974.

(4) R. A. Leone, "The Real Costs of Regulation," Harvard Business Review, Boston MA, November-December 1977.

(5) W. M. Capron, Editor, "Technological Change in Regulated Industries," The Brookings Institution, Washington DC, 1971.

(6) "Science Indicators," Report of the National Science Board, National Science Foundation, Washington DC, 1975.

(7) Capron, op. cit., "Technological Change in Regulated Industries"

(8) K. J. Arrow, "Economic Welfare and the Allocation of Resources for Invention," in The Rate and Direction of Inventive Activity: Economic and Social Factors, Princeton NJ 1962.

(9) R. R. Nelson, "The Allocation of Research and Development Resources: Some Problems of Public Policy," in Defense, Science, and Public Policy - Edited by Edwin Mansfield, Norton, New York, 1968.

(10) Battelle, "Interactions of Science and Technology in the Innovative Process" National Science Foundation Report NSF-BCL-C-567-73, Columbus OH, March 1973.

(11) A. H. Rubenstein and J. E. Ettlie, "Analysis of Federal Stimuli to Development of New Technology by Suppliers to Automobile Manufacturers" Final Report to U.S. Department of Transportation, Washington DC 20590, Report Nos. HS-803 291/DOT/TSC-NHTSA-78-22, March 1978.

(12) James Utterback and Albert Murray, "The Influence of Defense Procurement and Sponsorship of R&D on the Development of the Civilian Electronic Industry," MIT, Center for Policy Alternatives Report, 77-5, Cambridge MA, June 1977.

(13) RAND Corporation, Analysis of Federally Funded Demonstration Projects, Federal Report Number NBS-GCR-ETIP 76-05, April 1976.

(14) K. E. Knight, "A Study of Technological Innovation: The Evolution of Digital Computers," doctoral dissertation, Carnegie Institute of Technology, Pittsburgh, 1963.

(15) V. Miller and D. Sawers, "The Technical Development of Modern Aviation," Praeger New York, 1970.

(16) J. E. Tilton, "International Diffusion of Technology: The Case of Semiconductors," The Brookings Institution, Washington DC, 1971.

(17) W. R. MacLaurin, "Invention and Innovation in the Radio Industry," The Macmillan Company, New York, 1949.

(18) B. H. Klein, "The Decision Making Problem in Development," in The Rate and Direction of Inventive Activity: Economic and Social Factors, Princeton, 1962.

(19) W.J. Abernathy, "The Productivity Dilemma" Johns Hopkins University Press, Baltimore MD, 1978.

(20) M. H. Cooper, "Prices and Profits in the Pharmaceutical Industry," Pergamon, New York, 1966.

(21) H. D. Jacoby and J. D. Steinburner et. al. "Clearing the Air," Ballinger, Cambridge MA, 1973.

(22) S. C. Gilfillan, "The Sociology of Invention," Follett, New York, 1935.

(23) A. Nevins and F. Hill, "Ford: Expansion and Challenge," New York, Scribners, 1957.

(24) L. J. White, "The U.S. Automobile Industry Since 1945," Cambridge MA, Harvard University Press, 1971.

(25) White, op. cit., "The U.S. Automobile Industry," p. 243.

(26) Goodson, op. cit., "Federal Regulation of Motor Vehicles".

(27) White, op. cit., "The U.S. Automobile Industry," p. 234.

(28) White, op. cit., "The U.S. Automobile Industry," p. 245.

(29) Goodson, op. cit., "Federal Regulation of Motor Vehicles," p. 34.

(30) Goodson, op. cit., "Federal Regulation of Motor Vehicles".

(31) White, op. cit., "The U.S. Automobile Industry," p. 244.

(32) T. C. Austin and K. H. Hellman, SAE Transactions, Vol. 89 1973, "Passenger Car Fuel Economy - Trends and Influencing Factors".

(33) White, op. cit., "The U.S. Automobile Industry".

(34) C. Wilson, "Energy: Global Prospects 1985-2000", Report of the Workshop on Alternative Energy Strategies, McGraw-Hill, 1977 - (Emphasis added)

(35) C. Wilson, "Energy: Global Prospects 1985-2000", (Emphasis added).

(36) U.S. Department of Transportation, "The Report by the Federal Task Force on Motor Vehicle Goals Beyond 1980," September 1976.

(37) J. Claybrook, Administrator, National Highway Traffic Safety Administration, U.S. Department of Transportation. Speech before the Automotive News World Congress, Detroit MI, July 13, 1977. pp. 15-16.

(38) Abernathy, op. cit. "The Productivity Dilemma".

(39) U.S. Department of Transportation, "Data and Analysis for 1981-84 Passenger Automobile Fuel Economy Standards" - Summary Report, National Highway Traffic Safety Administration - February 1977.

APPENDIX A

Laws Regulating Product - Performance in the Auto Industry

Safety

1963-Roberts Bill - requiring cars bought by the Federal Government to meet safety standards (PL88-515).

September 9, 1963-National Traffic and Motor Vehicle Safety Act (PL89-563). Required the establishment of interim Federal motor vehicle safety standards by January 31, 1967 and revised standards one year later to be effective on all new cars within 180 days to one year after publication Included also a fire safety program.

January 31, 1967 National Traffic Safety Agency issued 20 auto safety standards for 1968 models.

October 13, 1967 Transportation Secretary Boyd made public 47 proposals to broaden existing safety standards: 18 standards to become effective on January 1, 1969 and 29 to become effective after that date.

March 18, 1970 Transportation Secretary Volpe announced his intention to require installation of air bags on the dashboard facing the front passenger seat as of January 1, 1972 (subsequently postponed date to January 1, 1973).

September 29, 1971 Douglas Toms, Administrator of NHTSA, announced a modification of the passive restraint standard. Air bags would be required for all seating positions on the 1976 models. Seat belts, under the new version, would have to be buckled before the car would start on 1974 models.

October 1972 Motor Vehicle Information and Cost Saving Act (PL92-513)- new bumper standards to reduce low speed collision damage.

October 1974 Motor Vehicle and School Bus Safety Amendments (PL93-492)- Required that manufacturers repair safety-related auto and fire defects free of charge to the owner. Stipulated that ignition-interlock system for seat belt would no longer be mandatory.

Exhaust emissions

1965 Motor Vehicle Air Pollution Control Act (PL89-272). Authorized Secretary of HEW to set standards limiting amount of pollutants that could be contained in auto emissions. Prohibited domestic sale of engines not conforming to standards.

1967 Air Quality Act (PL90-148). Research on pollution caused by fuel combustion including auto emissions.

December 5, 1969 Air Quality Act Amendments (PL91-137). Research on control of air pollution.

December 31, 1970 Clean Air Act Amendments of 1970 (PL91-604). Provided that model year 1975 cars must emit 90% less carbon monoxide and hydrocarbons than model year 1970 cars. Nitrogen oxides in 1976 model cars must be reduced 90% compared with model year 1971.

March 27, 1973 Clean Air Act Extension (PL93-15). Authorization for air pollution and auto emission control programs established in 1970.

June 22, 1974 Energy Supply and Environmental Co-ordination Act of 1977 (PL93-319). Delayed CO and hydrocarbon emission standards until September 30, 1977 and final standards for nitrogen oxides until September 30, 1978.

Fuel Economy

October 1974 FEA announced that it did not intend to achieve the goal of 40% increase in gasoline mileage by legislation. The auto companies did not directly oppose or support the goal.

September 1975 The Federal Trade Commission put together an "interim guideline" requiring that all ads with fuel economy claims carry EPA city and highway test results, with a warning that consumers might not get the same percentage.

December 22, 1975 Energy Policy and Conservation Act (PL94-163) - required that the average fuel economy for passenger cars manufactured or imported by any one manufacturer in any model year after 1977 be no less than 18 mpg in 1978, 19 mpg in 1979, 20 mpg in 1980, 27.5 mpg in 1985 (with the Secretary of DOT setting interim levels between 1981-84). Secretary empowered to make adjustments at the request of manufacturers if other Federal standards - such as clean air - reduce the fuel economy of cars.

APPENDIX B

R & D Project Sample

This appendix lists the sample of three hundred and thirty-three R&D projects conducted during the period 1973-1977 which was analyzed and described in Section 3 of this report. The sample was compiled from two sources which propose to offer a comprehensive catalogue of Federal Programs. The projects included from these two sources are those that pertain to automotive technology; and fuels in reference to energy efficiency, combustion, engine and power train programs, materials, emissions, and safety and automotive transportation. The two sources are:

1. Smithsonian Science Information Exchange (SSIE). This is a computerized data base of current R&D projects maintained by the Smithsonian Institute.

2. Inventory of Energy Research Development, 1973-1975. This is a report describing pertinent R&D projects that was prepared for the Subcommittee on Energy Research and Development and Demonstration of the U.S. House of Representatives Committee on Science and Technology.

The project lists which follow are generally organized in three sections according to areas of regulatory mission. The final section of the appendix lists the organizations that either sponsored or conducted the projects. The projects are related to the performing and/or sponsoring organizations by a numerical cross reference code in the project list:

Section	Areas
I	Fuel Economy/Alternative Fuels
II	Pollution Avoidance/Control
III	Product Safety
IV	Organization (Sponsor and/or Performer)

The following project listings are from 80 column punched cards which include summary information about each project, coded in alphanumeric form in eight fields according to the following format.

Field	Coded Information
1. Project Reference Designator	Columns 8-17 (on punched cards)

A. For projects from the Smithsonian (SSIE) data base this is an alphabetic and numeric reference beginning with two or three alphabetic characters.

B. For projects from the Energy R&D Inventory this is a four digit number (columns 12-15)

2. Abbreviated Title of Research	Columns 18-48
3. Sponsor of Project	Columns 49-54

Provision for 6 column alpha abbreviation. Recorded to 3 digit numerals (cols 49-51) - See Section IV of Appendix.

4. Performer of Project	Columns 55-60

Similar provisions as above, 3 digit numerals (cols 55-57) See Section IV of Appendix.

5. R&D Expenditure	Columns 61-67

The cumulative expenditure reported on the project in thousands of dollars, correct to two decimal places. The columns provided for this information are:

6. Use of Research	Columns 68-74

If research is a survey or for gathering general information, column 68 will show 1

If research is for regulatory support, or rule making, column 69 will show 1

If research is on a non-civilian product, for the government, column 70 will show 1

If research is basic, i.e.,"research where the primary aim of the investigator is a fuller knowledge or understanding of the subject under study rather than a practical application thereof," then column 71 will show 1

If research is applied, i.e.,"research is directed toward the practical application of knowledge," column 72 will show 1

If research is developmental, i.e.,"research aims at the systematic use of knowledge directed toward the design and production of useful proto devices and systems - it does not include quality control or routine product-testing," column 73 will show 1

If research is for "improving methods and processes of manufacture," column 74 will show 1

7. Subject of Research — Columns 75-78

If main thrust of the research is to lower product cost, column 75 will show 1

If the main aim of research is to achieve fuel economy or to come up with alternative fuels to alleviate the fuel crisis, column 76 will show 1

If the primary purpose of research is to avoid or control pollution, column 77 will show 1

If the primary objective is to improve product features, column 78 will show 1. More specifically if the feature relates to safety column 78 will show "S"

8. Application Descriptors — Columns 79-80

A. Radicalness of Technology — Column 79

The research projects have been classified as under:

	Column 79
1. unspecified or current technology	blank
2. incremental technological change	1
3. changes in combustion technology	
a) external combustion	E
b) rotary engine	R
c) turbine	T
4. electric vehicle	L
5. alternate fuel	F
6. weight-reduction by material substitution	M

B. Vehicle to Which Research is Applicable Column 80 (final entry)

Column 80 will carry the following coded information

Vehicle	Code
Cars	blank
Trucks	T
Buses	B

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1. Fuel Economy/Alternative Fuels

1	2	3	4	5	6	7	8
NTA 36 1	METHANOL AS MOTOR FUEL	616	616		1	1	F
ZUG 2629	PROP & PERF CHC NON PETR FUELS	101	101		1	1	F
ZUG 2784 1	HYDROCARBON UTILISATION	101	101	5058	1	1	F
BO 193 1	DEV OF A NICKLE ZINC BATTERY	421	421		1	1	L
BT 730 1	HI ENERGY DENSITY SECD BATTERY	421	421		1	1	L
CA 733	ELECTRIC CAR MODIFICATION	416	417		1	1	I
GZO 441	TEST UNIV OF FLORIDA HYBRID BUS	001	207	5	1	11	LM
BI 38209 1	ESTIMATE MV FUEL CONSUMPTION	001			1	1	
BI 45807 1	REPORT ON PVT ENERGY CONSUMPTN	001	621		1	1	
BJ 5	SONIC JET IGNITION	901	536	185	1	11	
BJ 154 1	LEAN MIXT COMBN & INSTRUMTATION	901	601	110	1	11	
BP 521	GASOLINE CONSUMPTION MODEL	109	537		1	11	S
GZ 58625	ENERGY CONS PUT OF DIESL TRUCKS	001	208		1	1	T
ZBA 6347	SHIRLEY HI WAY BUS ON FREEWAY	103	103	362	1	1	B
AD 21365	FUELS FOR AUTO TRANSPORTATION	104	708		1	1	F
BG 883 1	COMBN OF MULTICOMP HC FUELS	901	602	104	1	11	F
BI 107244	LO EMISSION FUELS FOR VEHICLES	001	614	20	1	1	F
BU 638 1	TRANSITION TO LIQUID H2 AS FUEL	538	538	30	1	1	F
GMA 2311	IMPACT STUDY ON USE OF ALT FUEL	104	527		1	1	F
GTR 371 1	STRATIFIED CARGE ENGINE	801	420	350	1	11	
WZ 2960	METHANOL AS A VEHICULAR FUEL		623	301	1	1	F
ZBA 6040 2	HYDROGEN FUTURE FUEL	103	103	185	1	1	F
ZH 41530 1	EOA/NASA AUTO GAS TURBINE PROGM	107	107		1	11	T
ZUG 2911	FUEL SELEC & CONSERVATION	101	101		1	1	F
ZUG 2917	EPA CO OPERATIVE PROJECTS	101	101		1	1	F
ZZD 33	EVAL OF DIES PROPLSN FOR TAXI	001	002		1	1	
NTA 39	METHANOL AS MOTOR FUEL	616	616	14	1	1	F
PGN 14	SYNTHETIC H2 FUELED IC ENGINE	505	505	20	1	11	F
4607	ALTERNATIVE AUTO POWER SYSTEMS	104	513	245	1	1	
4612	AUTOMOTIVE COMPRESSOR & TURBINE	104	107	212	1	1	T
4614	AUTOMOTIVE COMPONENTS	402	402		1	1	
4630	GROUND VEHICLE EFFICIENCY	107	107	55	1	111	T
4667	VAC AUTO FUEL SHUT OFF VALVE	402	402		1	11	
4673	PRE CHAMBER ENGINE PROGRAM	306	306	15	1	11	
4675	ALTERNATE POWER PLANTS RESEARCH	306	306	560	1	11	T
4676	GAS TURBINE POWERPLANT	306	306	5300	1	1111	T
4677	CHRYSLER GAS TURBINE BASELINE	104	306	7900	1	1111	T
4679	COMBUSTION IN H2 FUELED TRANSP.	001	622	10606	1	1	
4680	RES & DEV OF DIESEL ENGINES	419	419		1	11	T
4682	ROTARY ENGINE MOD HI SPEED TECH	403	403		1	11	R
4683	COMBUSTION RESEARCH-ROT ENGINE	403	403		1	11	R
4685	PRE CHAMBER SPARK IGNITED ENGN	304	304		1	11	
4685	ALTERNATE ENGINE PROGRAMS DIESL	304	304		1	11	1T
4687	PRE CHAMBER SPARK IGNITED ENGN	304	304		1	11	
4688	PROCO STRATIFIED CHARGE	304	304		1	11	E
4689	LO EMISSION COMBUSTOR DEVELPMT	429	429		1 1	11	
4690	CERAMIC MATERIAL TO IMPROVE EFF	429	429		1	1	
4691	STRATIFIED CHARGE ENGN COMBN	304	623		1	11	
4692	BASIC ENGINE COMBUSTION STUDIES	623	623	113	1	11	
4693	ICENGINE/H2 GENERATOR PERFM	104	107	300	1	11	
4694	LEAN MIXTURE ENGINE TEST&EVALN	002	107	300	1	11	
4702	OPTIMAL STRATFN IN RECIPR. ENGN	901	602	59	11	11	
4707	CONVERSION OF BUS ENGINES	404	404		1	1	B
4708	ROTARY ENGINE FUELS/COMBUSTION	801	505	130	1 1	1	R
4711	ENGINE EFFICIENCY & EXHAUST EMM	001	625	86	1	11	
4712	DIESEL TECHNOLOGY	801	430	2567	1	111	T
4713	STRATIFIED CHARGE ENGINE	801	420	539	1 1	11	
4714	ADVANCED MIL PROPULSION SYSTEMS	801	603	271	1 1	11	
4715	ADVANCED TURBINES	801	801	719	1 1	1 1	T
4719	DOT CO OPERATIVE PROJECT	101	101		1	11	

1	2	3	4	5	6	7	8
4720	EVALUATION OF AUTO GAS TURBINES	405	405		1	1 1 1	
4721	UTILISATION OF WASTE HEAT	604	604	7		1 1	
4729	ELECTRIC DRIVE CAR RESEARCH	203	606		1	1	L
4639	AIR BEARING FOR TURBINES	104		90	1	1	I
4661	GASOLINE OPERATED IC ENGINES	402	402		1	1	
4660	EXH GAS RECIRCULATING VALVE	402	402		1	1	
4659	ELIMINATE EXHAUST GAS CIRCULN.	402	402		1	1	
4658	RECIRCULATOR CONTROL VALVE	402	402		1	1	
4629	TRACTOR TRAILER COMBINATIONS	107	107	90	1	1	I
4656	UTILISATION OF LNG FOR AUTOFUEL	538	538	500	1	1	T
4653	GASOLINE FUEL INJECTION SYSTEM	304	418	1850	1	1	
4732	COMBN IN STRAT CHARGED ENGINE	901	601	190	1	1 1	
4734	EVALN OF METHANOL/GASOLINE	001	608	56	1	1 1	
4736	USE OF ENERGY MANAGEMENT	001	603	140	1	1	
4738	VEHICLE ENGINE DEVELOPMENT	801	406	930	1 1	1 1	1
4740	CLOSED BRAYTON CYCLE BUS ANGINE	429	429		1	1 1	Ed
4743	DEVELOPMENT OF HOT GAS ENGINES	001	623	79	1	1 1	1
4652	DIESEL FUEL INJECTION SYSTEM	304	418	1532	1	1 1	T
4650	INJECTION NOZZLE & HOLDER UNIT	418	418	196	1	1 1	T
4649	DESIGN OF IMPROVED FLYWHEEL	209	209	13	1	1	
4616	ALTERNATE ENGINE	801	304	505	1	1 1	F
4753	COMPOUNDING IC ENGINE FOR AUTO	104	502	888	1	1	E I
4756	ELECTRIC VEHICLES	407	407	57	1	1 1	LT
4757	UTILISATION OF ELECTRIC VEHICLE	202	510	15	1	1 1	L
4759	ELECTRIC VEHICLE	408	701	101581	1	1	LF
4760	ELECTRIC CAR SYSTEM MODELING	304	304		1	1 1	L
4766	LEAD ACID ELECTRIC VEHICLE SYST	421	421		1	1 1	ET
4767	ELECTRIC VEHICLE	701	409	10	1	1	LI
4771	ELECTRIC VEHICLE R&D	630	630	20	1	1	LF
4773	EVC ELECTRIC WORK VEHICLE PROJ	201	201		1	1	L
4774	ELEC VEH USE & ENERGY CONSUMPN	410	410	15	1	1	L
4776	ELECTRIC CAR EVALUATION	411	411	102601	1	1	L
4777	ELECTRIC CAR MODOFICATION	411	411	1510	1	1	L
4778	DEV OF TRANSP ENERGY SYSTEMS	511	511	27	1	1	L
4780	HYBRID POWER SOURCE	801	801		1 1	1	L
4783	ELECTRO MECHANICAL DESIGN STUDY	702	512		1	1	I
4784	RED AUTO ENERGY CONSUMPTION	901	513	140	1	1	
4785	HIGHWAY VEHICLE RETROFIT EVAL	002	513	200	1	1	
4788	USE OF ALUMINIUM IN VEHICLES	422	422		1	1	A
4789	ELECTRONIC FUEL INJECTION	423	423		1	1 1	1
4608	AERODYNAMIC DEVICES FOR TRUCK	901	514	989	1	1	I
4641	AIR DRAG REDUCTION DEVICES	901	501	7240	1	1	I
4792	VACUUM ELECTRIC SWITCH	402	402		1	1	
4793	IDLE AIR COMPENSATOR	402	402		1	1	
4794	VACUUM REGULATOR FOR SPEED CONT	402	402		1	1	
4795	CHEAP POWER SAVING ENGN COOLING	402	402		1	1	I
4796	TEMP MOD VAR SPD COOLING FAN DR	402	402		1	1	I
4999	DEV OF LOCK UP CLUTCH	402	402		1	1	
4828	FUEL ECONOMY OF EMISSION CONTRL	705	520		1	1 1	
4832	VEHICLE OPTG PARAMETERS	104	505	58	1	1 1	I
4833	AUTOMATIC TRUCK TRANSMISSION	413	413		1	1 1	I
4837	IMPROVED FUEL CONVERSION EFFY	801	801	150	1	1 1	
4843	FUEL SELECTION & CONSERVATION	101	110		1	1	
4844	AUTOMOTIVE ENERGY EFFY PROGRAM	001	002	8800	1	1	
4847	FUEL CONSUMPTION BY TRAC TRALRS	901	611	113	1	1	1
4848	ALCOHOLS AS VEH FUEL EXTENDERS	001	608	60	1	1	F
4850	USE OF ENERGY MANAGEMENT	603	603	180	1	1	
4851	NATURAL GAS FUELED VEHICLES	414	414	11	1	1	F
AU 727 1	OPERATION OF A H2 FUELED ENGINE	708	607		1	1 1	F
BG 589	WORKSHOP FOR NUM SIM OF COMBN	901	522	325	1	1 1	

1	2	3	4	5	6	7	8
BG 894	NUM MODELING OF COMBUSTION	901	522	1116	1	11	
BI 149 1	LO EMISSION ENGINES 1970 ACT	306	306	11723	1	11	
BI 25404	CALIFORNIA STEAM BUS PROJECT	001	204		1	1	EB
BI 38780	EXHAUST SILENCER DESIGN	001	523		1	1	T
BI 38781	BASELINE STUDY INTAKE EXH ETC	001	512		1	1	T
BI 45288 1	DEV OF UNCONVNAL AUTO PROPULSN	001	524		1	1	1
BI 82733	COOLING AIR FLOW DUTY CYCLES	706	525		1	1	
BI 107445	RECIPROCATING BRAYTON CYCLE	626	626		1	11	
BI 136054	INVESTGN OF METHANOL GAS BLENDS	205	543		1	1	F
BJ 154 1	LEAN MIXTURE COMBN & INSTRUMNTN	901	601	110	1	11	
BO 277	EFFECT OF SHORTTERM DRIVE TRAIN	901	513	14913	1	1	
BS 981 1	ALT COMP IGNITION ADVANCE SYST	402	402		1	11	
BU 597	HI EFF LO POLN ENGINE H2 ENRICH	107	107	1000	1	11	
BU 930	EMULSIFIED FUELS FOR DIESEL	901	602	136	1	11	
BU 933	AUTO ENGN COMB WITH EXCESS AIR	901	605	200	1	11	
GMA 2226 1	CHC OF METHANOL/GASOLINE BLEND	104	628	210	1	1	F
4810	ADVANCED VEHICLE PROPULSION SYS	429	429		1	1	1
4812	AUTO ACCESSORY PWR REQUIREMENT	104	429		1	1	
4814	COMPUTER SIMULATION-DESIGN	432	432		1	1	
4815	IMPROVE NEW CAR FUEL ECONOMY	109	516	88	1	1	
4816	ALUMINIUM AUTO APPLICATIONS	424	424		1	1	M
4819	AERODYNAMIC DRAG REDUCTION	002	107	55	1	1	
4823	OPTIMISATION OF SPARK IGNITION	517	610	15	1	1	
4827	OPERATING CHARACTERISTICS STUDY	001	519	50	1	1	
GMA 2369	ADVANCED FUEL METERING DEMO	104	427	16289	1	11	
GMA 2457 1	CHC & RES OF METHANOL & METHYL	104	614		1	11	F
GSQ 929 1	PLAN REDUCED AUTO ENRGY CONSMPN	901	513	152	1	1	
GSQ 953	ALCOHOL PETROLEUM AIR MIXTRS	901	544	1370	1	1	F
4802	TORQUE CONVERTER WITH LOCKUP	306	306	970	1	1	
4803	DIAGNOSTIC INSPECTION SYSTEM	004	515	349	1	11	
4807	ROAD RATING PROGRAM	705	704		1	11	
4809	S 3E	429	429		1	11	
GZ 55968 1	TEST & EVALUATE AUTO POWER PLNT	101	101		1	11	
GZ 58622	FUEL ECONY DRIVER AID DEVICES	001	801		1	1	
GZ 58723	PERF CRIT LEAN MIXTURE ENGINE	001	623		1	11	
GZO 202	LEAN MIX ENGN TEST & EVAL PROGM	001	107	150	1	11	
GZO 400	DATA BASE FOR LT WT DIESEL ENGN	001	302		1	1	
GZO 439	TECH ASSIST FOR DIESL TAXI EVAL	001	707		1	1	
4800	POWER CONSUMPTION ON AUTO TIRES	004	503	60	1	1	
4801	SPARK IGNITION RECIP ENGINES	412	412		1	11	
GZO 651	AIR MODULATED FLUIDIC FUEL INJN	001	615		1	11	
	LEAN MIXTURE ENGINE	001	623		1	1	
JAH 16 1	HYDROGEN ENERGY APPLICATIONS	304	533	762	1	1	F
JAH 25 1	ALTERNATE ENGN PROGM, FAST BURN	304	304		1	11	

II. Pollution Avoidance/Control

1	2	3	4	5	6	7	8
GZO 441	TEST UNIV OF FLORIDA HYBRID BUS	001	207	5	1	11	LR
GZ 58843	STUDY OF DRIVE TRAIN COMPONENT	001	546		1	11	1
BP 521	GASOLINE CONSUMPTION MODEL	109	537		1	11	S
GZ 58629	EMISSION CTRL DEVICES	001	107		1	1	
4609	AUTO POWER TRAIN & VEH COMPNENT	303	303		1	1	
4673	PRE CHAMBER ENGINE PROGRAM	306	306	15	1	11	
4675	ALTERNATE POWER PLANTS RESEARCH	306	306	560	1	11	T
4676	GAS TURBINE POWERPLANT	306	306	5300	1	1111	T
4677	CHRYSLER GAS TURBINE BASELINE	104	306	7900	1	1111	T
4680	RES & DEV OF DIESEL ENGINES	419	419		1	11	T
4682	ROTARY ENGINE MOD HI SPEED TECH	403	403		1	11	R
4683	COMBUSTION RESEARCH-ROT ENGINE	403	403		1	11	R
4685	PRE CHAMBER SPARK IGNITED ENGN	304	304		1	11	
4685	ALTERNATE ENGINE PROGRAMS DIESL	304	304		1	11	11
4687	PRE CHAMBER SPARK IGNITED ENGN	304	304		1	11	
4688	PROCO STRATIFIED CHARGE	304	304		1	11	F
4689	LO EMISSION COMBUSTOR DEVELPMT	429	429		1 1	11	
4691	STRATIFIED CHARGE ENGN COMBN	304	623		1	11	
4692	BASIC ENGINE COMBUSTION STUDIES	623	623	113	1	11	
4693	ICENGINE/H2 GENERATOR PERFM	104	107	300	1	11	
4694	LEAN MIXTURE ENGINE TEST&EVALN	002	107	300	1	11	
4695	EMISSION REDN OF AUTO GAS TURBN	107	107	168	1	1	1
4696	COMPUTER SIMULATION OF IC ENGN	107	107	50	1	1	
4702	OPTIMAL STRATFN IN RECIPR. ENGN	901	602	59	11	11	
4706	CATALYTIC COMBUSTOR TECHNOLOGY	104		200	1	1	
4709	DIESEL EMISSIONS	104	505	16210	1	1	T
4711	ENGINE EFFICIENCY & EXHAUST EMM	001	625	86	1	11	
4712	DIESEL TECHNOLOGY	801	430	2567	1	111	T
4713	STRATIFIED CHARGE ENGINE	801	420	539	1 1	11	
4714	ADVANCED MIL PROPULSION SYSTEMS	801	603	271	1 1	11	
4719	DOT CO OPERATIVE PROJECT	101	101		1	11	
4720	EVALUATION OF AUTO GAS TURBINES	405	405		1	111	
4721	UTILISATION OF WASTE HEAT	604	604	7		11	
4730	STUDY OF COMBN IN STRATIFIED	901	607		1	1	
4731	EFFECTS OF FUEL ADDITIVES ON EM	104	601	67	1	1	
4732	COMBN IN STRAT CHARGED ENGINE	901	601	190	1	11	
4734	EVALN OF METHANOL/GASOLINE	001	608	56	1	11	
4657	EMISSION SYSTEMS-HEAT EXCHANGER	402	402	115	1	1	
4630	GROUND VEHICLE EFFICIENCY	107	107	55	1	111	T
4616	ALTERNATE ENGINE	801	304	505	1	11	T
4663	AIR PUMP VALVES	402	402		1	1	
4664	THERMALLY CONTROLLED SWITCH	402	402		1	1	
4665	CONTROLLED FLUID JET CARBURETOR	402	402		1	1	
4666	MULTI AIR PASSAGE CARBURETOR	402	402		1	1	
4667	VAC AUTO FUEL SHUT OFF VALVE	402	402		1	11	
4738	VEHICLE ENGINE DEVELOPMENT	801	406	930	1 1	11	1
4739	AUTOMOTIVE RANKINE CYCLE ENGINE	104	609	235	1	1	E
4740	CLOSED BRAYTON CYCLE BUS ANGINE	429	429		1	11	ER
4741	LOW EMISSION CLOSED BRAYTON ENG	429	429		1	1	E
4743	DEVELOPMENT OF HOT GAS ENGINES	001	623	79	1	11	1
4745	AUTO POLLUTION ABATEMENT	901	610	51	1	1	
4752	LOW EMISSION ENGINES (RANKINE)	104	502		1	1	E
4756	ELECTRIC VEHICLES	407	407	57	1	11	LI
4757	UTILISATION OF ELECTRIC VEHICLE	202	510	15	1	11	L
4760	ELECTRIC CAR SYSTEM MODELING	304	304		1	11	L
4766	LEAD ACID ELECTRIC VEHICLE SYST	421	421		1	11	LI
4652	DIESEL FUEL INJECTION SYSTEM	304	418	1532	1	11	1
4650	INJECTION NOZZLE & HOLDER UNIT	418	418	136	1	11	1
4618	STIRLING ENGINE	304	304		1	1	E
4647	ROLE OF FUEL DROP SIZE	104	601	160	1	1	1

1	2	3	4	5	6	7	8
4643	ALTERNATE ENGINE RANKINE CYCLE	304	502			1 1	E
4617	FAST BURN ENGINE	304	304		1	1	1
4789	ELECTRONIC FUEL INJECTION	423	423		1	11	1
BG 589	WORKSHOP FOR NUM SIM OF COMBN	901	522	325	1	11	
BG 894	NUM MODELING OF COMBUSTION	901	522	1116	1	11	
BI 449 1	LO EMISSION ENGINES 1970 ACT	306	306	11723	1	11	
BI 107445	RECIPROCATING BRAYTON CYCLE	626	626		1	11	
BI 134949	TECHNIQUES FOR RED ENGINE NOISE	301	301		1	1	
BJ 154 1	LEAN MIXTURE COMBN & INSTRUMNTN	901	601	110	1	11	
BJ 622	KEY ISSUES CONCERN AUTO EMISSN	901	526	606	1	1	
BS 973 1	IDLE FUEL SHUT OFF SOENOIDS	402	402		1	1	
BS 974 1	AUTO THROTTLE SOLENOID CONTROLS	402	402		1	1	
BS 979	VAC LINE PURGE VALVE	402	402		1	1	
BS 981 1	ALT COMP IGNITION ADVANCE SYST	402	402		1	11	
BS 982 1	VAC PRESSURE DELAY VALVES	402	402		1	1	
BS 983 1	VALVES TO PERFORM SIGNAL SWITCH	402	402		1	1	
BS 987	THERMAL CANISTER PURGE VALVE	402	402		1	1	
BU 597	HI EFF LO POLN ENGINE H2 ENRICH	107	107	1000	1	11	
BU 930	EMULSIFIED FUELS FOR DIESEL	901	602	136	1	11	
BU 933	AUTO ENGN COMB WITH EXCESS AIR	901	605	200	1	11	
CD 285	PHEN FOR ODOR FORMATION	901	620		1	1	
GMA 2265	LO EMISSION CAT COMB TECHNOLOGY	104	107		1	1	1
GMA 2314	PRE CHMBR EMISSION CNTRL DEVICE	104	513	54	1	1	
GMA 2369	ADVANCED FUEL METERING DEMO	104	427	16289	1	11	
GMA 2457 1	CHC & RES OF METHANOL & METHYL	104	614		1	11	F
GMA 2745 1	LO VEH EMISSION STUDY	104	529	66318	1	1	
GMA 2817 1	NITRIC OXIDE FORMATION IN O ENG	104	547		1	1	
GMA 3093	EFFECT OF AUTO PARTS ON EMISSN,	104	548	9774	1	1	
GMA 3171	BASIC TEST FOR EMISSION CONTROL	104	530	14313	1	1	
GSE 5626	DYN RESP OF CATALYTIC CONVE9TER	901	605	229	1	1	
GSQ 950	STR, CHRG SPARK IGNITION ENGN,	901	607		1	1	
GZ 48546 1	EFFECTS OF CRACKED EXH MANIFOLD	001	530		1	1	
GZ 55968 1	TEST & EVALUATE AUTO POWER PLNT	101	101		1	11	
GZ 58723	PERF CRIT LEAN MIXTURE ENGINE	001	623		1	11	
GZU 202	LEAN MIX ENGN TEST & EVAL PROGM	001	107	150	1	11	
GZU 622	SMALL IC ENGINE NOISE	001	503		1	1	
GZO 651	AIR MODULATED FLUIDIC FUEL INJN	001	615		1	11	
JAH 25 1	ALTERNATE ENGN PROGM, FAST BURN	304	304		1	11	
JAH 27 1	ALT ENGINE WANKEL	304	304		1	1	
JBT 22	REDUCTION OF IC ENGINE EMISSION	545	545		1	1	
4808	EMISSIONS,DRIVEABILITY,FUEL CHC	704	704		1	1	
4809	S 3E	429	429		1	11	
4828	FUEL ECONOMY OF EMISSION CONTRL	705	520		1	11	
4832	VEHICLE OPTG PARAMETERS	104	505	58	1	11	1
4837	IMPROVED FUEL CONVERSION EFFY	801	801	150	1	11	
4849	MV DIAGNOSTIC INSPN DEMO PROJ	004	612	2435	1	1	
AU 18623	TURBINE AND RANKINE ENGINES	104	425		1	1	1
AU 727 1	OPERATION OF A H2 FUELED ENGINE	708	607		1	11	F
PGN 14	SYNTHETIC H2 FUELED IC ENGINE	505	505	20	1	11	F
ZH 41530 1	EOA/NASA AUTO GAS TURBINE PROGM	107	107		1	11	F
ZQA 73488 3	DIAGN TECHNIQUES FOR AUTO EQUIP	801	801		1	1	
ZQA133736	OXIDATION STABILITY OF OILS	801	801		1	1	
AD 21528 1	ALTERNATE FUELS REDUCN OF POLN	104	618		1	1	F
BG 883 1	COMBN OF MULTICOMP HC FUELS	901	602	104	1	11	F
4801	SPARK IGNITION RECIP ENGINES	412	412		1	11	
4803	DIAGNOSTIC INSPECTION SYSTEM	004	515	349	1	11	
4806	OCTANE NUMBER REGMT SURVEY	705	704		1	1	
4807	ROAD RATING PROGRAM	705	704		1	11	
GOA123769	RES ON FUEL&LUB RELATED EMISSN	801	505	125	1	1	
GTR 371 1	STRATIFIED CARGE ENGINE	801	420	350	1	11	

1	2	3	4	5	6	7	8
4790	EXHAUST GAS RECIRCULATOR VALVE	402	402		1	1	
4791	THERMAL CONTROL VALVE	402	402		1	1	1

1	2	3	4	5	6	7	8
HI135452	IMPACT TOLERANCE IN FREE FALLS	709	601		1	S	
BI135772	DEV CRASHWORTHY AUTO STRUCTURES	433	433		1	1 S	
HI136056	PATTERN OF SEATBELT USE FAT ACC	205	205		1	S	
BI136059	URBAN USE OF BELT & STRAP USAGE	205	205	1	1	S	
BO 280	REGULATING THE AUTOMOBILE	901	623	12550	1	1S	
HS 957 1	FUEL TANK VALVES TO STOP SPILLS	402	402		1	S	
HS 989	PRESSURE-VAC RELIEF VALVE	402	402		1	1S	
GB232147 3	INVESTIGATION OF VEH ACCIDENTS	706	601		1	S	
HV 89	DEV OF RISK METHODOLOGY-SYS SAF	001	607	12056	1	S	
GZ 38833 3	SAFETY REL DEFECTS OF TRIUMPH	001	710		1	S	
GZ 55563 2	ALCOHOL SAFETY INTERLOCK SYSTEM	001	549		1	S	
GZ 45968 2	DYNAMICS OF ARTICULATED VEHICLE	001	622		1	S	I
GZ 55674 1	CHANGE IN HIWAY SAFETY ENVIRON	001	631		1	S	
GZ 55680 1	DEV & APP OF VEH RATING CRITER	004	425		1	S	
GZ 55685 1	CONSUMER INFO CRASH TEST PROGM	004	547		1	S	
GZ 55686 1	CONSUMER INFO CRASH TEST PROGM	004	503		1	S	
GZ 55688 1	RECORDER-TO MONITOR DUMMY IMPCT	004	550		1	S	
GZ 55713 1	SURVIVABILITY-LAT,ROLLOVER COLN	004	503		1	S	
GZ 58081 1	IV INT CONGRESS ON AUTO SAFETY	004	547		1	S	
GZ 58089 1	SAFETY BELT USAGE SURVEY	004	551		1	S	
GZ 58386 1	EVAL OF AUTO WEIGHT REDUCTION	001	632		1	S	
GZ 58448	AUTO EMI RESEARCH	004	111		1	S	
GZ 58703	FRONTAL STIFFNESS IMPACT TEST	004	503		1	S	
GZ 58709	PERF TEST ON IMPROVED RESTR SYS	004	547		1	S	
GZ 58710	EVALUATION OF GM AIR CUSHION	004	547		1	S	
GZ 58711	PERF TEST ON IMPROVED RESTR SYS	004	505		1	S	
GZ 58772	SAFETY DEFECTS INVESTIGATION	004	552		1	S	
GZ 58773	LAB TEST PROCEDURE-AIR BAG CHEV	004	305		1	S	
GZ 58774	TRAILER BRAKE PERFORMANCE	004	601		1	S	
GZ 58789	EVALUATION OF DRIVER VEH DATA	004	549		1	S	
GZ 58790	RESPONSE TO REAR IMPACT	004	633		1	S	
GZ 58792	EFFECTIVENESS OF BELT WARNING	004	551		1	S	
GZ 58800	ON BOARD VEHICLE SENSOR TECH	004	553		1	S	
GZ 58885	ASPIRATION INFLATION TECHNIQUE	004	503		1	S	
GZ 58886	ANALYSIS OF LEVEL 2 RESTR SYS	004	631		1	S	
GZ 58894	ENGINEERING MODEL OF FUTURE VEH	004	302		1	S	
GZM 51 2	TEST SEAT BELT ASSY STD 209	004	554		1	S	
GZM 233 1	DIAG INSPN DEMO PROJECT	004	612	243500	1	S	
GZM 235 1	DEF OF 1985 FAMILY AUTO	004	503		1	11S	
GZO 204	ACRS ACCIDENTS IN SF REGION	004	629		1	S	
GZO 205	ACRS ACCIDENTS IN SW REGION	004	505		1	S	
GZO 206	ACRS ACCIDENTS IN FAR WEST REG	004	634		1	S	
GZO 242	MODELING TECH FOR GRADE CROSS	001	527		1	S	
GZO 373	MV DIAG INSPN DEMO PROJECT	001	210	5531	1	S	
GZO 487	PARTS RETURN PROGRAM	001	555		1	S	
GZO 514	STUDY OF RIGID POLYURETHANE	001	433		1	S	
GZO 535	PUERTO RICAN MANDATORY BELT LAW	001	211		1	S	
GZO 639	EXTENDED MODEL OF AUTO SAFETY	001	556		1	S	
GZO 675 1	VALIDATION OF CRASH VICTIM SIM	001	503		1	S	
GZO 698	LT WT STRUCTURE IN AUTO MATL	001	112		1	1 S	M
NOH 739	DESIGN & EVAL OF NEW (NECK*	635	635		1	S	

IV. Organization (Sponsor and/or Performer)

Organization	Code		
DEPARTMENT OF TRANSPORTATION			
	DEPARTMENT OF TRANSPORTATION	001	DOT
	TRANSPORTATION SYSTEMS CENTRE	002	TSC
	NATIONAL TRANSPORT CENTRE	003	NTC
	NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION	004	NHTSA
FEDERAL DEPARTMENTS/AGENCIES OTHER THAN DOT,DOD AND NSF			
	BUREAU OF MINES	101	BURMIN
	NATIONAL BUREAU OF STANDARDS	103	NBS
	ENVIRONMENTAL PROTECTION AGENCY	104	EPA
	NATIONAL AERONAUTIC & SPACE AGENCY	107	NASA
	FEDERAL ENERGY AGENCY	109	FEA
	ENERGY RESEARCH DEVELOPMENT AUTHORITY	110	ERDA
	US DEPT. OF COMMERCE	111	US COM
	US SMALL BUSINESS ADMINISTRATION	112	SMBSAD
STATE GOVERNMENTS/AGENCIES			
	PUBLIC SERVICE COMPANY, OKLAHOMA	201	PSC OK
	CITY GOVT OF SEATTLE	202	SEATLE
	PUBLIC SERVICE COMMISSION, COLORADO	203	PSCCOL
	STATE OF CALIFORNIA	204	CALIF
	VIRGINIA STATE	205	VIRG
	NEBRASKA STATE GOVT	206	NEBGOV
	FLORIDA STATE GOVERNMENT	207	FLASTE
	MAINE STATE GOVERNMENT	208	MNESTE
	OKLAHAMA STATE OF	209	OKLA
	WASHINGTON DC	210	WASHDC
	PUERTO RICAN TRAF. SAF. COMMISSIONER	211	PUERC
MOTOR VEHICLE MANUFACTURERS			
	INTERNATIONAL HARVESTOR	301	INTHAR
	VOLKSWAGON	302	VW
	AMERICAN MOTORS CORPORATION	303	AMC
	FORD MOTOR COMPANY	304	FORD
	GENERAL MOTROS CORPORATION	305	GMC
	CHRYSLER CORPORATION	306	CHRYS
CONVERTERS/ SUPPLIERS OF COMPONENTS, MATERIALS & ENERGY			
	OWENS ILLINOIS	401	OWILL
	BORG WARNER	402	BRGWRN
	CURTISS WRIGHT	403	CURTWR
	ROHR INDUSTRIES	404	ROHR
	UNITED AIRCRAFT	405	UA
	WHITE ENGINES INC	406	WHITE
	ATLANTIC CITY ELECTRIC CO TRANSPORTATION	407	ATLELC
	CONSOLIDATION EDISON	408	CONSED
	KANSAS GAS & ELECTRIC CO	409	KGECO,
	PUGET SOUND POWER & LIGHT	410	PUGET
	SOUTHERN CALIFORNIA EDISON	411	SCEDIS
	CHAMPION SPARK PLUG	412	CSPLUG
	SUND STRAND	413	SNDSTR
	WISCONSIN GAS	414	WISGAS
	ALABAMA POWER COMPANY	415	ALBPWR
	PENNSYLVANIA ELECTRIC COMPANY	416	PELELC
	SOUTHERN CALIFORNIA EDISON	417	SCEDS[illegible]
	AMBAC	418	AMBAC
	CUMMINS ENGINE	419	CUMMIN
	TEXACO	420	TEXACO
	GOULD	421	GOULD
	ALCOA	422	ALCOA
	BENDIX	423	BENDIX
	KAISER ALUMINUM	424	KAISER
	GENERAL ELECTRIC	425	GE
	EXXON	426	EXXON

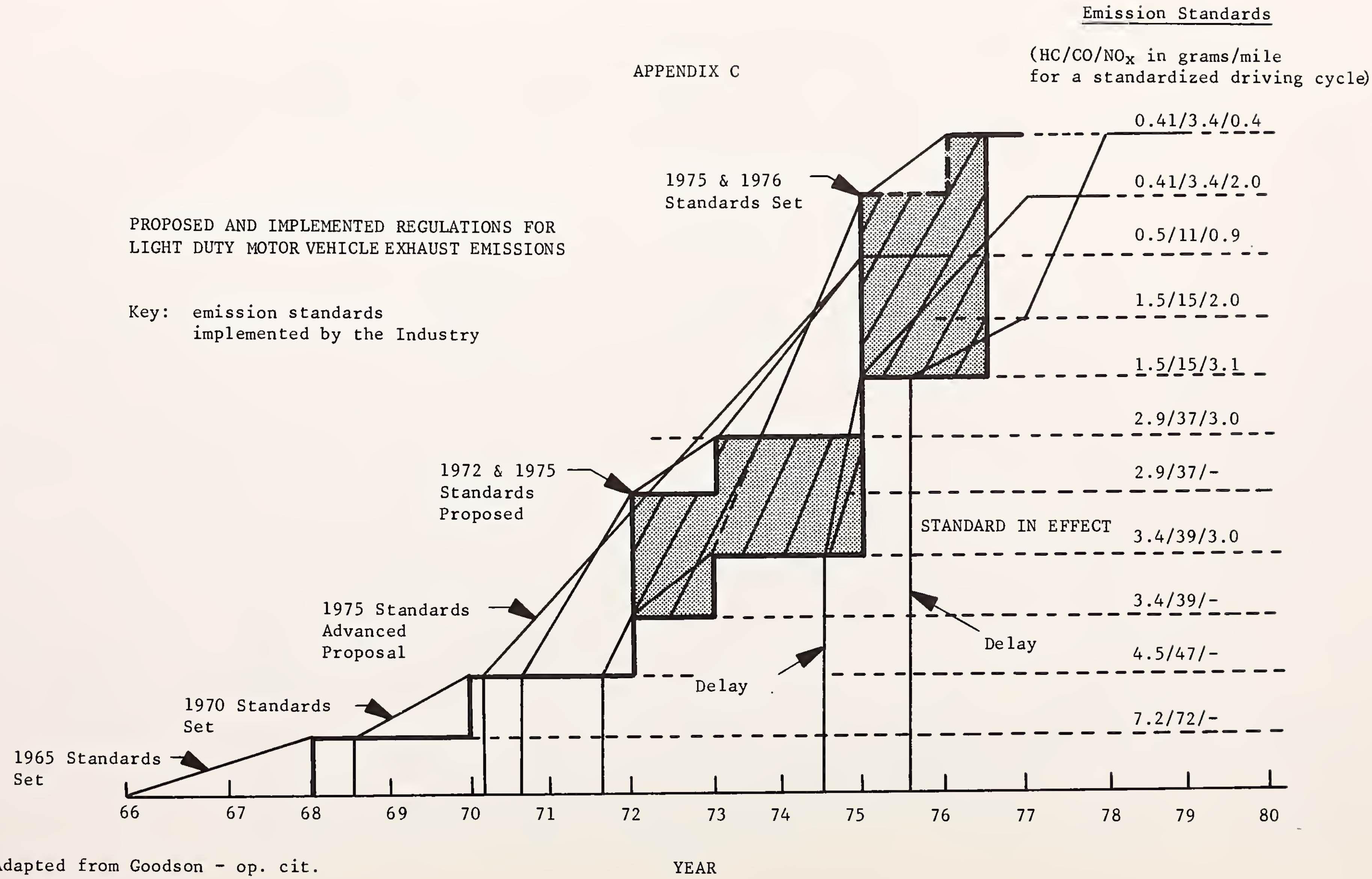
Organizations	Codes	
COLT	427	COLT
GARRETT	429	GARRET
TELEDYNE	430	TELDYN
POWERMATIC	431	PWRATC
IBM	432	IBM
BUDD COMPANY	433	BUDD
PRIVATE AND INDUSTRIAL RESEARCH INSTITUTIONS		
SYSTEMS SCIENCE & SOFTWARE	501	SYSCSO
THERMO ELECTRON	502	THEREL
CALSPAN	503	CALSPN
SOUTH WEST RESEARCH INSTITUTE	505	SW RES
PRECISE POWER	507	PRCPWR
SCIENTIFIC ENERGY SYSTEMS	508	SCENSY
STEAM POWER SYSTEMS	509	STPOSY
BATELLE PACIFIC NORTHWEST LABORATORY	510	BATELP
SPECIAL SYSTEMS CO	511	SPSYST
WILLIAM M. BROBECK & ASSOC.	512	WMBASC
AERO SPACE	513	AERSPC
AEROVIRONMENT	514	AEROVM
COMPUTER SCIENCES CORPORATION	515	COMPSC
JACK FAWCETT ASSOC	516	JFASSC
PENNSYLVANIA RESEARCH CORPORATION	517	PRC
RESEARCH TRIANGLE INSTITUTE	519	RTI
RUNZHEIMER	520	RUNZMR
SCIENCE APPLICATION	522	SCAPP
DONALDSON	523	DWLDSN
INTERNATIONAL RESEARCH & TECH CORP	524	IRTC
WYLE LABORATORY	525	WYLE
ECONOMICS & SCIENCE PLANNING	526	ESP
STANFORD RESEARCH INSTITUTE	527	SRI
STEAM ENGINE SYSTEMS CORPORATION	528	STESC
AUTOMOTIVE TESTING LABORATORY	529	ATTSTL
GENERAL ENVIRONMENT	530	GENENV
R L POLK & COMPANY	531	POLK
CHILTON	532	CHILTN
BILLINGS ENERGY RESEARCH CORPORATION	533	BILLNG
GENERAL RESEARCH CORPORATION	534	GRC
ARGONNE NATIONAL LABORATORY	535	ARNLAB
PHYSICS INTERNATIONAL COMPANY	536	PIC
ENERGY & ENVIRONMENTAL ANALYSIS	537	E&EA
BEECH AIRCRAFT	538	BEECH
SUNPWR	540	SUNPWR
STEMCO	542	STEMCO
SHTC	543	SHTC
WAYNE	544	WAYNE
AT&T	545	AT&T
ARTHUR D LITTLE	546	ADL
ULTRA SYSTEMS INC	547	ULTSYS
OLSON	548	OLSON
SYSTEMS TECHNOLOGY ASSOCIATES, INC	549	STA
RAMAN SCIENCE CORPORATION	550	RSC
OPINION RESEARCH CORPORATION	551	ORC
GENERAL ADJUSTMENT BUREAU INC	552	GAB
AVCO CORPORATION	553	AVCO
DAYTON T. BROWN	554	DTBRN
KAPPA SYSTEMS INC	555	KAPPA
PUGH ROBERTS ASSOCIATES	556	PRASS
UNIVERSITIES		
UNIV. OF MICHIGAN	601	MICHGN
UNIV OF PRINCETON	602	PRNCTN

Organizations	Code	
WISCONSIN	603	WISCON
UNIV. OF ARIZONA	604	ARIZNA
UNIV OF CALIFORNIA, BERKELEY	605	CALBKY
UNIV OF COLORADO	606	COLORD
UNIV OF ILLINOIS	607	ILLIN
NIV OF MISSOURI	608	MISSRI
CARNEGIE MELLON UNIV	609	CARMEL
PENN STATE	610	PENSTE
UNIV OF MARYLAND	611	MRYLND
UNIV OF TENNESSEE	612	TENNSE
UNIVERSITY OF SANTA CLARA	614	STCLAR
UNIVERSITY OF TEXAS	615	TEXAS
TEXAS A & M	616	TEX AM
UNIVERSITY OF NEBRASKA	617	NEBRSK
SOUTHERN UNIVERSITY A&M COLLEGE	618	SUA&M
STATE UNIVERSITY OF NEW YORK	619	SUNNY
NORTHWESTERN UNIVERSITY	620	NW UNV
CALIFORNIA INSTITUTE OF TECHNOLOGY	621	CIT
CORNEL UNIVERSITY	622	CORNEL
MASSACHUSETTS INSTITUTE OF TECHNOLOGY	623	MIT
PURDUE UNIVERSITY	624	PURDUE
STANFORD UNIVERSITY	625	STANFD
HAWAII UNIVERSITY	627	HAWAII
DREXEL UNIVERSITY	628	DREXEL
MIAMI UNIVERSITY	629	MIAMI
BOSTON UNIVERSITY	630	BOSTON
UNIVERSITY OF NORTH CAROLINA	631	NCLNA
DARTMOUTH COLLEGE	632	DART
NEW MEXICO STATE UNIVERSITY	633	NMXSTU
UNIVERSITY OF SOUTHERN CALIFORNIA	634	USOCA
STATE UNIVERSITY OF OHIO	635	OHIO
<u>INDUSTRY/ TRADE ASSOCIATIONS</u>		
ELECTRIC VEHICLE COUNCIL	701	EVC
ELECTRIC POWER RESEARCH INST	702	EPRI
CENTRE FOR ENVIRONMENT & MANAGEMENT	703	CEM
CO-ORDINATION RESEARCH COUNCIL	704	CRC
AMERICAN PETROLEUM INSTITUTE	705	API
MOTOR VEHICLE MANUFACTURERS ASSOCN.	706	MVMA
METRO TAXI CAB BOARD OF TRADE	707	MTBT
INSTITUTE OF GAS TECHNOLOGY	708	IGT
INSURANCE INST FOR HIGHWAY SAFETY	709	IIHS
AUTOMOTIVE CLUB OF SOUTHERN CALIFORNIA	710	ACSC
<u>DEPARTMENT OF DEFENCE</u>		
DEPARTMENT OF DEFENSE	801	DOD
<u>NATIONAL SCIENCE FOUNDATION</u>		
NATIONAL SCIENCE FOUNDATION	901	NSF

APPENDIX C

PROPOSED AND IMPLEMENTED REGULATIONS FOR
LIGHT DUTY MOTOR VEHICLE EXHAUST EMISSIONS

Key: emission standards implemented by the Industry

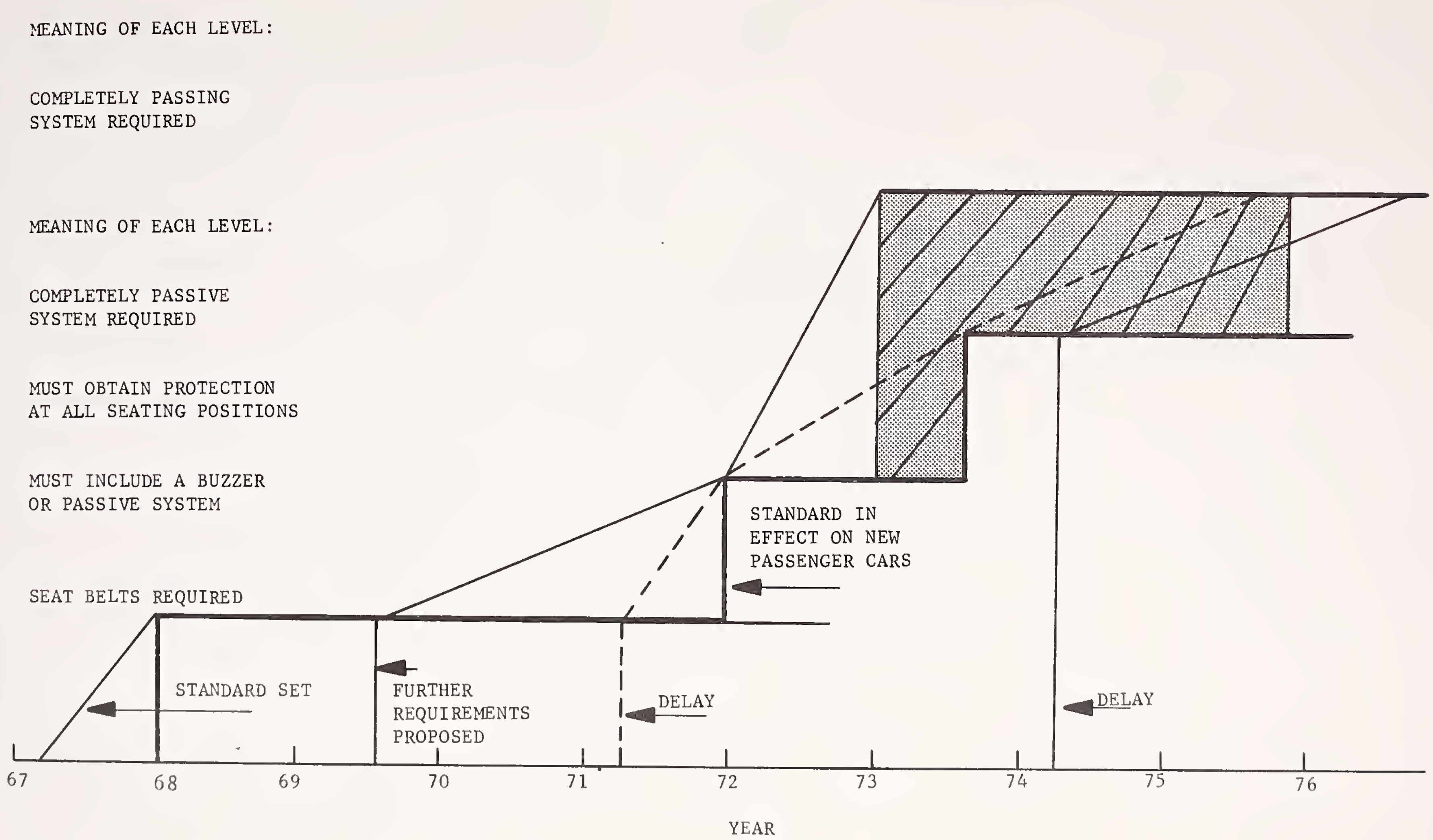


Adapted from Goodson - op. cit.

APPENDIX D

PROPOSED AND IMPLEMENTED REGULATIONS FOR
OCCUPANT CRASH PROTECTION IN
NEW PASENGER CARS

Key: Standards implemented by Industry

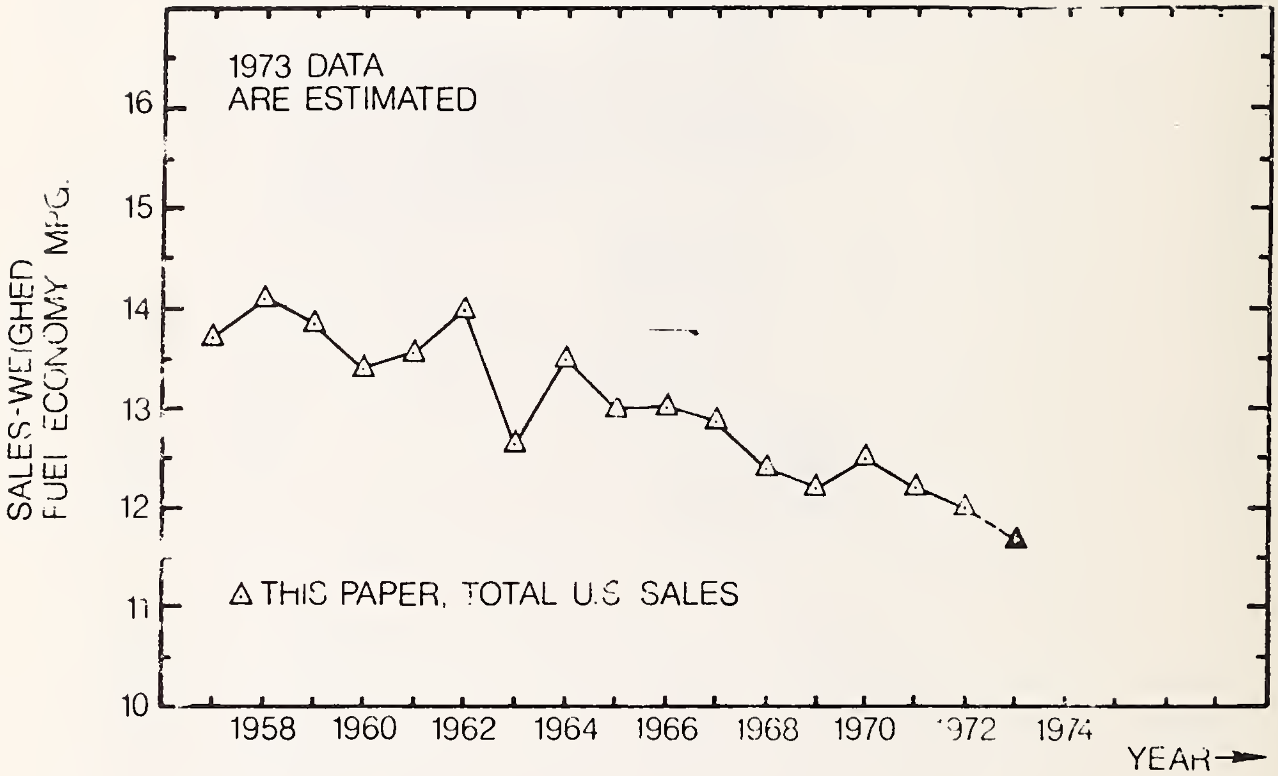


Adapted from Goodson - op. cit.

APPENDIX E

TRENDS IN SALES-WEIGHTED FUEL ECONOMY

1957-72



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