Winter 1995

A Nonlinear Dynamic Method for Supporting Large-Scale Decision-Making in Uncertain Environments

Wayne Woodhams
Old Dominion University

A NONLINEAR DYNAMIC METHOD FOR SUPPORTING

LARGE-SCALE DECISION MAKING

IN UNCERTAIN ENVIRONMENTS

Wayne Woodhams
B.S.E.E. May, 1968, Clarkson College of Technology
M.B.A. May, 1972, Adelphi University

A Dissertation Submitted to the Faculty of
Old Dominion University in Partial Fulfillment of the
Requirements for the Degree of

DOCTOR OF PHILOSOPHY

ENGINEERING MANAGEMENT

OLD DOMINION UNIVERSITY
December, 1995

Approved by:

____
Dr. Laurence D. Richards (Director)

____

____

____

ABSTRACT

A NONLINEAR DYNAMIC METHOD FOR SUPPORTING LARGE-SCALE DECISION MAKING IN UNCERTAIN ENVIRONMENTS

Wayne Woodhams
Old Dominion University
Director: Dr. Laurence D. Richards

This research developed a methodology for supporting decision making by reducing uncertainty in decision environments which are too large, dynamic and complex to be treated by traditional quantitative and simulation techniques. These environments are complex because of the free choice associated with human involvement, and the existence of a large number of interrelated factors which influence the outcomes of the decision process. They are dynamic because the ground rules affecting those interrelationships are constantly changing. Uncertainty cannot be treated probabilistically, since identification of a full set of outcomes and factors of influence is not possible.

The venue for the investigation was the infrastructure which supports commercial space launch activities in the United States. The issue treated was whether it would be advisable to make large capital investment in that infrastructure.

The problem was approached using the principles of Chaos Theory and Nonlinear Dynamics, in a manner similar to that used by Priesmeyer (1992). The intent was to engender a more systemic view of the environment and

approach analysis by examining marginal changes, over a period of ten years, in factors which tend to influence the outcome. The objective was to develop hypotheses which, when validated, will provide a new perspective for decision makers from which to enhance the robustness of these kinds of decisions.

The methodology, which evolved over several years of preliminary research, involved identification of sectors of the commercial space infrastructure, isolation of the more important decision factors, identification and solicitation of knowledgeable respondents from the various infrastructure sectors, development of a computerized qualitative data gathering instrument, and graphical analysis of data represented by phase plane diagrams. Although there was little evidence of "classical" chaotic behavior in the data, the analysis was able to isolate those nonlinear dynamic relationships between decision factors which appeared most likely to provide information regarding system behavior. One hypothesis was developed directly from that observation. A second resulted from the development of an aggregate measure of the level of uncertainty (and, consequently, investment risk) inherent in the decision environment.

DEDICATION

To my wife, Sam, and son, Chris, without whose understanding, support, encouragement and prodding, this endeavor may not have been concluded. Also, to my mother, Lucille, without whose steadfast support I never would have made it through undergraduate school.

ACKNOWLEDGMENTS

In the absence of a degree program in the discipline of Engineering Management, I would certainly not have pursued a terminal degree. My thanks are extended to all of those people in the College of Engineering and Technology and the Department of Engineering Management who have contributed their energies to make the program what it is. I also wish to express individual thanks to my dissertation committee: Dr. Larry Richards and Dr. Billie Reed, for providing guidance and feedback throughout the process, and to Dr. Barry Clemson and Dr. Jim Schwing for their valuable insights in creating the final product. Others in the Department to whom I owe a debt of gratitude include Dr. Derya Jacobs, Dr. Fred Steier, Dr. Chuck Keating and Ms. Gerri Dutton, who provided valuable advice, assistance and encouragement. Collegial interaction with fellow doctoral students, especially Shelley Gallup, also provided valuable insight and information. Finally, although they remain anonymous, my thanks are extended to those who participated in the data gathering and analysis which supported this research.

TABLE OF CONTENTS

Page

ACKNOWLEDGMENTS iii

LIST OF FIGURES AND TABLES vii

Chapter

1. INTRODUCTION 1

Problem Statement 1

Venue of Investigation 3

Purpose of the Research 4

2. UNDERLYING THEORY OF RESEARCH (LITERATURE REVIEW) 6

Strategic Decision Theory and Policy Formulation 7

Robust (Investment) Decision Theory 14

Forecasting 16

Chaos Theory and Nonlinear Dynamics 21

Departure From Existing Theory 26

3. METHODOLOGY 28

Background 28

Theoretical/Conceptual Framework of the Research 30

Identification of Sectors of the Environment 32

Page

Identification of Factors Affecting Decision Making 37

Formal Data Gathering 43

Human Subjects 43

The Survey Instrument 44

Selection and Recruitment of Survey Respondents 48

Data Analysis 52

Data Processing 52

Development of Marginal Change Data 53

Development and Analysis of Phase Plane Diagrams 55

Periodicity 57

Limit Cycles 61

Development of System Uncertainty Index 62

Summary of Methodological Process 66

4. FINDINGS AND RESULTS 68

Filtered Marginal Change Data 68

Phase Planes for Pair-wise Comparison of Marginal Changes in Decision Factors 69

System Uncertainty Index 78

Summary and Hypotheses 83

Page

Limitations 83

Biases 84

Validity of Data and Results 85

Implications of Results 87

5. CONCLUSIONS AND REFLECTIONS 91

REFERENCES 95

APPENDIX

A. LITERATURE AND CONTACTS USED AS INFORMAL DATA SOURCES 100

B. SURVEY INSTRUMENT SOFTWARE SCREENS AND RESPONDENT INSTRUCTIONS 108

C. SOLICITED SURVEY RESPONDENTS 143

D. RAW RESPONDENT DATA 145

E. RATIONALE AND DATA FOR FILTERED MARGINAL CHANGE DATA 158

F. PHASE PLANE DIAGRAMS 166

G. PHASE PLANE ANALYSIS DATA 212

H. SYSTEM UNCERTAINTY INDEX CHARTS FOR INDIVIDUAL FACTORS 215

I. PHASE PLANE DIAGRAMS WITH "NEXT POINT" PROJECTIONS 221

LIST OF FIGURES AND TABLES

Figure Page

2-1. Theoretical Perspectives of the Research 8

2-2. Taxonomy of Forecasting Methodologies (Armstrong) 19

2-3. Forecasting Taxonomy Showing New Methodology 27

3-1. Sectors of the Environment 33

3-2. Correlation Matrix - Decision Factors to Environmental Sectors 50

3-3. Phase Plane: Legal/Regulatory Environment vs. Launch Cost 56

3-4. Phase Plane: DoD Support vs. Launch Cost 63

3-5. Phase Plane Diagram Showing SUI Vector 65

3-6. Methodological Process 67

4-1. Classical Limit Cycle Behavior 70

4.2. Phase Plane With "Next Point" Projections 72

4-3. Most Stable Inter-factor Relationships 74

4-4. Composite System Uncertainty Index 80

Table

3-1. Survey Question Set 46

4-1. Filtered Marginal Change Data 68

4-2. Most Stable Inter-factor Relationships 75

4-3. System Uncertainty Indices 82

CHAPTER 1

INTRODUCTION

Problem Statement

Most large-scale decision making is done in a dynamic, highly complex environment. For purposes of this research, "large-scale" decision making is defined as that which:

- involves commitment of large sums of money (on the order of millions of dollars) and/or similarly valued assets;
- is performed in an environment which extends beyond the decision maker's own organization and over which she or he has little or no control; and
- attempts to influence outcomes which take a significant amount of time (perhaps decades) to fully manifest themselves.

The environment is characterized as "dynamic" because the forces and relationships which affect the decision and its outcomes are constantly changing. Being populated and influenced primarily by humans and their interactions, it is also characterized by nonlinear relationships and a high degree of uncertainty regarding the future. The number of factors is too great, and the interactions too complex, to allow analysis and comprehension through any kind of linear approach.

Ashby (1956), in discussing the Law of Requisite Variety contends that, in order to fully regulate a system, the regulator must have at least as much variety as that system. In terms of decision making, that could be restated as, "In order to make a decision which guarantees an optimal outcome, the decision maker must have at least the variety presented by the environment in which the decision is to be made." Since this is obviously not possible, in order to make some sensible decisions, ways must be found to reduce the variety in the environment, increase the variety of the decision maker or, preferably, both.

Eoyang (1978) discusses these issues in terms of organizations coping with unpredictable environments. He notes that organizations tend to try to increase their variety to match that of the environment by organizing with greater structural differentiation, more elaborate integration and more decentralized conflict management. He goes on to say that organizations try to reduce the variety in the environment by exercising some control over it through proactive interaction (forming cartels, selection of board members, developing long-term supply contracts, etc.). He suggests that a third method of reducing variety in the environment is consistent with Ashby's work, that is, to reduce the variety of potential outcomes of actions by adjusting goals.

But what can be said about the decision maker who needs to decide whether or not to commit substantial amounts of resources in a market whose complex, nonlinear and dynamic characteristics create the kind of uncertainty in which probabilistic methods of analysis do not apply, because, at a given decision point, there exists neither a closed set of known potential outcomes, nor a quantifiable set of variables and relationships? This kind of uncertainty has been termed "primary uncertainty."

Some ways of dealing with the variety of the decision maker, including "robust" decision making (Gupta and Rosenhead, 1968, and Rosenhead, Elton and Gupta, 1972) have been addressed. Adjustment of goals and objectives through "satisficing" techniques has also been addressed (March and Simon, 1958). An area that remains for investigation is how to reduce (or at least find a way of coping with) the variety imposed on the decision maker by the environment.

Venue of Investigation

The chosen setting for the research has current relevance in the technological business community. Over the past four decades, exploration and exploitation of space has become a significant contributor to humankind's scientific and technological knowledge. Only recently, by comparison, has some of the commercial potential of space been exploited. Thus far, the only spaceborne commodity which has proven commercially viable is information and communication. The reason is that the cost of access to space is still prohibitive for most other kinds of activities. The question, then, which provides the venue for this research is: "Should an investment be made to develop the infrastructure to support commercial space launch activities?" It is easily seen that there are various technological, political, market, financial and other factors which will influence the viability of such ventures. Middleton (1995) contends that the track record of space launch market predictions is not very good, and that it would be prudent for investors to seek advice from a wide range of sources regarding assessment of factors capable of influencing market growth. Most of these factors, however, are not directly measurable: they interact in complex, nonlinear ways, and they are not predictable over the timeframe required to establish the vehicles and infrastructure to provide cost effective space access.

Purpose of the Research

The purpose of the research is to add to the body of knowledge and supporting tools for strategic decision making, policy formulation and forecasting in the kinds of environments characterized herein. Toward this purpose, the investigation will employ qualitative data gathering methods and an analysis based on the principles of nonlinear dynamics and chaos theory to investigate the complex macroscopic relationships between factors which affect the viability of investments in commercial space infrastructure.

The research is investigative in nature, and not intended to stand as proof of a given hypothesis. It is an examination of the data of a sample study, with the intent of generating hypotheses regarding the utility of the methodology to provide meaningful information to decision makers.

The methodology and hypotheses are generalizable to a broad range of decision environments which embody the complexity and dynamic interrelationships characteristic of the environment examined herein. One such scenario might be the strategic decision by an automobile manufacturer regarding development of an "alternatively powered" vehicle. It contains many of the same kind of uncertain elements: emerging (and currently unknown) technologies, dependence on government regulation, influence of public opinion, level of competition and others.

CHAPTER 2

UNDERLYING THEORY OF RESEARCH (LITERATURE REVIEW)

The objective of this research is to examine a new methodology for supporting large-scale strategic decision making in environments characterized by nonlinear relationships of variables and primary uncertainty. Primary uncertainty, which will be discussed in greater detail subsequently, can be operationally defined as that situation in which probabilistic methods of analysis do not apply because, at a given decision point, there exists neither a closed set of known potential outcomes, nor a quantifiable set of interactions and relationships between variables. As stated by Mendell (1985), all systems of interest are open systems, susceptible to invasion by outside forces which cannot be identified until they affect the system. Those forces are the "unk-unks" (unknown unknowns).

The underlying theory comes from three domains. First, of course, is the theory that supports strategic decision making itself, and particularly that which deals with non-probabilistic decisions. Secondly, since strategic decision making involves some attempt at adapting to an uncertain future, there is also an element of (long-range) forecasting, with its associated grounding theory.

Thirdly, this research attempts to deal with the complex, dynamic, nonlinear relationships by applying analytical techniques derived from chaos theory. The theoretical perspective of the research emerges from these domains as shown in Figure 2-1.

Strategic Decision Theory and Policy Formulation

Thompson and Strickland (1981) define organizational strategy and policy as activities associated with giving the organization purposeful direction toward stated goals and objectives, and allocating resources toward that end. As described in Chapter 1, the venue of this research involves a strategic decision regarding allocation of resources to develop space launch infrastructure, as opposed to some other venture. This specific scenario is clearly a subset of the general definition given by Thompson and Strickland. Entities interested in the outcome of the research would include commercial companies seeking increased profits and/or market share, and government agencies seeking to stimulate economic development.

It can be said that all decisions of any consequence made by organizations involve some degree of uncertainty regarding the future. Uncertainty, however, has always posed a problem for decision makers. Gul and Lantto (1990) have stated:

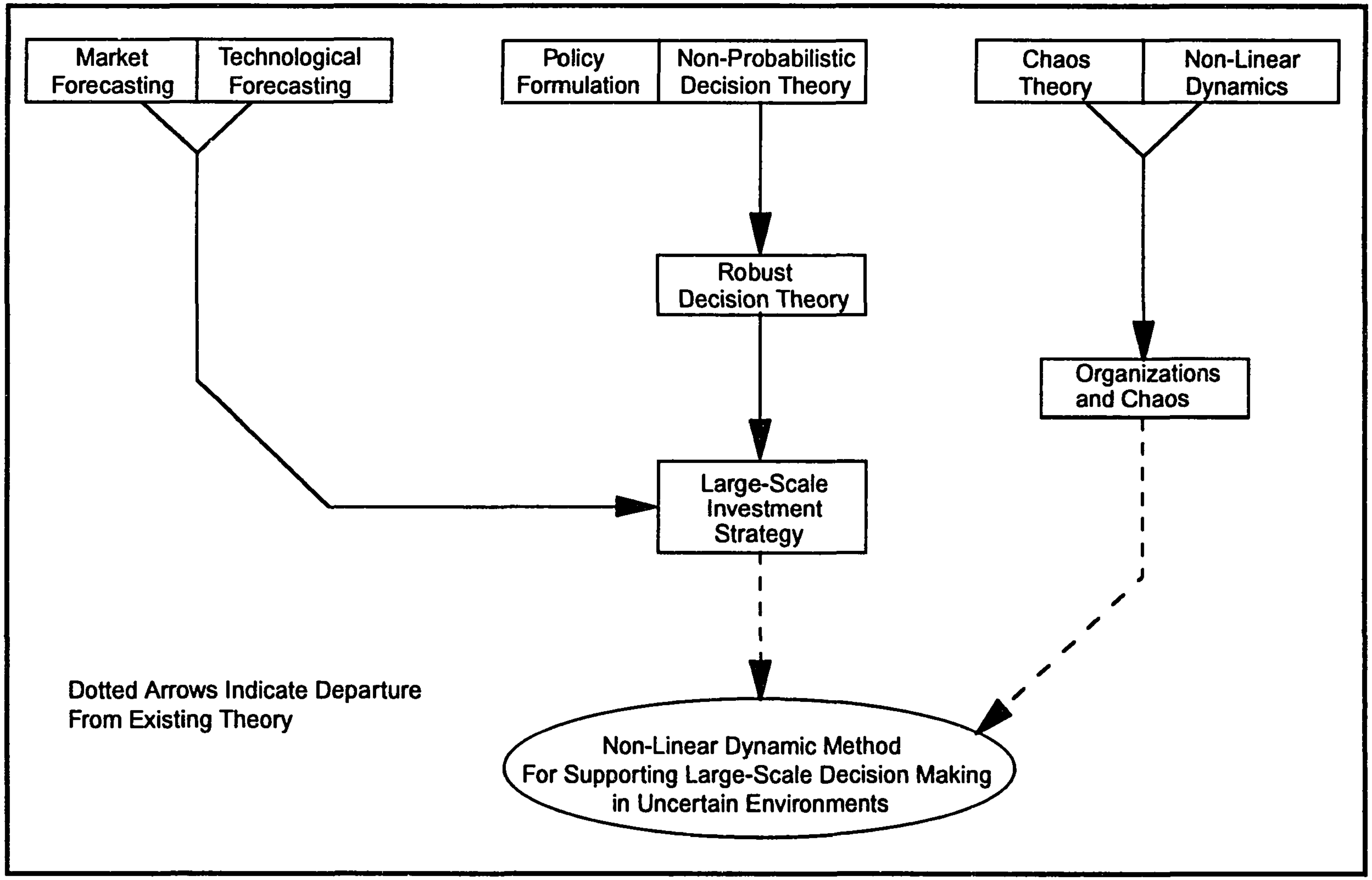


Figure 2-1. Theoretical Perspectives of the Research

> . . . . it is unlikely that any theory of choice under uncertainty which is consistent with what an economist might consider rational behavior will be capable of accommodating all observed behavior in actual choice situations, nor is it clear that a purely descriptive theory...will add substantially to our understanding of choice under uncertainty. (Gul and Lantto 1990, 173)

Aiginger (1987) does not treat "uncertainty proper" (i.e., no probability function can be formed regarding the variable of interest). He differentiates between risk and uncertainty proper, the former being where probabilities can be estimated. He contends that:

> As a consequence of uncertainty proper, agents regress to simple rule of thumb or convention, they behave in a conservative way reacting only to dramatic changes in the environment. (Aiginger 1987, 31)

The views of Gul, Lantto and Aiginger notwithstanding, the literature describes many tactics for dealing with uncertainty, but all make assumptions regarding the bounds of the uncertainty: that is, they either ignore what is admittedly unknowable or lump unknowables in with known factors. The majority of decision methodologies (Clemen (1991), Dyckman et al. (1969), Hill et al. (1979), Newbold (1986), Radford (1981), Easton (1980), Jedamus and Frame (1969), Holloway (1979) and many others) involve some kind of probability model, whether it be subjective (Savage, 1954), Bayesian or based on statistical probability distributions (Binomial, Poisson, Exponential, Normal, Beta, Bernoulli, Geometric, Multinomial, and others).

Much of decision theory in light of uncertainty has revolved around the concept of Expected Utility (Stigler, 1950; Allais and Hagen, 1979; Machina, 1982; Fishburn, 1970, 1982; Schniedler, 1989; and Prelec and Loewenstein, 1991). But this framework, as well, requires assignment of probabilities for decision variables. Other theories, including prospect theory (Kahneman and Tversky, 1979) and regret theory (Loomes and Sudgen, 1982) also require assignment of probabilities to variables or states of nature. Karni (1985) also describes decision making under uncertainty in terms of the basic notions of states of nature, acts, and consequences; the states of nature being governed by either objectively or subjectively determined probabilities.

Many of these same authors discuss expected value, risk profiles, dominance criteria, sensitivity analysis and the maximin, maximax and rationality rules for choosing (acting, in Karni's terminology) among alternative strategies, but these rely on a knowledge of (or at least a guess at) the full set of possible states of nature, and/or estimation of probabilities for those states. To further complicate the issue, research by Bolger and Wright (1993) suggests that the validity of probability judgments made by "domain experts" to support decisions of this kind is suspect.

Some recent research examines new ways to support decision making. Mehrez et al. (1995) propose that a powerful approach for describing systems that are concurrent, parallel, asynchronous, distributed and non-deterministic involves representation using Petri Nets, which serve as meta-models for complex decision problems. Petri Nets can replace decision trees, with the advantages of providing some computational utility and the ability to represent situations under certainty and (probabilistic) uncertainty. Dagsvik (1994) has developed a method for generating choice probabilities for consumer demand (states of nature) based on the stochastic properties of the demand function and "consumption bundle vectors" of attributes of the decision outcomes.

Some attempts have been made to address the uncertainty issue via specialized computer software. Cohen (1985) developed an expert system shell called SOLOMON which employs a system of endorsements to reinforce or refute uncertain propositions. The results, however, are difficult to interpret and the propositions difficult to rank. Henrion, Morgan, Nair and Wiecha (1986) developed a computer model called Demos which was intended to aid policy analysts in handling uncertainty and risk. But a criterion of its design was that uncertain values be represented as probability distributions.

There has been research and methodologies have been proposed to support decision making without the use of probabilities. Kelsey (1993) discusses a method which can be used under *partial* uncertainty by a decision maker who does not have the luxury of waiting for complete information. He derives an ordinal scaling scheme for ranking potential states of nature in terms of their likelihood of occurrence. The decision maker then would choose the action with the best payoff assuming that the most likely state of nature will occur.

Beenhakker (1975) suggested a form of sensitivity analysis that entailed making some contingency assumptions (based on the assumption that you must have some idea of what might happen) at the outset of strategic planning. However, he makes no provision to do any sequential planning, relating all contingencies back to time zero. Yager (1980) developed a "theory of possibility" based on fuzzy set theory, which was used by Tonn (1986, 1991) in his research regarding environmental policy decisions. Tonn observed that there were many instances in long range planning in which even subjective probabilities could not be generated. His model involved development of a "possibility function" which described all possible future worlds so that policy analysts and planners could plan to eliminate those undesirable outcomes, and let society chart a more desirable, but unspecified course. Similarly, Mason and Wilson (1987) propose that a process they term "future mapping" be used to develop desirable end states - possibilities, not forecasts - and "event streams" that identify what must happen along the way for them to get there. Then as each milepost (decision point) is reached, the organization will know what action will lead them toward one of the desirable end states. These models are developed in brainstorming meetings and use matrices as visual displays.

Others, including Cohen and Jaffrey (1980) and Arrow and Hurwicz (1972) have looked at decision making under what they term "complete ignorance," meaning that the decision maker has no knowledge of how the states of nature might influence the outcomes of actions taken. Cohen and Jaffrey establish a set of axioms which define decision criteria without ascribing probabilities to events. The method does, however, rely on the definition of a complete set of events and outcomes, and bases decisions on comparison between "extremal values" of acts. Arrow and Hurwicz do not presuppose a fixed set of states of nature, posing the problem as a choice of action from a given set, when the consequences of such action are functions of an unknown state of nature.

One element of the decision environment examined herein that none of the previously cited authors address is its dynamic nature: the fact that it can change during the decision process. Hey (1993) performed research in which a dynamic simulation with live subjects proved that few were capable of making optimal decisions in a dynamic environment with only three variables changing. He concludes that much of the lack of predictability in real-life markets results from sub-optimal decisions made by those who assume that the environment is predictable. The literature failed to reveal any research into the use of chaos theory and/or nonlinear dynamics principles to address decision making issues, other than Priesmeyer's work which is discussed below.

Robust (Investment) Decision Theory

Wittrock (1979) describes planning at the policy level as follows:

> (It) involves the systematic preparation of decisions that may have long term consequences, and the aim of this activity is not the specification of future commitments, but to guarantee that policy makers will in the future have as wide a range of options open as possible. (Wittrock 1979, 268)

In two papers, Gupta and Rosenhead (1968) and Rosenhead, Elton and Gupta (1972) contend that uncertainty in strategic planning and investment strategy is characterized by those situations "...in which it is impossible to attribute probabilities to the possible outcomes of any decision" (1972, p. 416). They treat a special class of problem in which unpredictable future events may influence the outcomes of sequential investment decisions, using a plant location problem with an unpredictable product demand as an illustration. They introduce the concepts of robustness and stability as measures, at any given decision point in the planning period, of flexibility of the strategic plan to provide a "good" (not optimal) result in light of future uncertainty. They accomplish this by employing the technique of satisficing (March and Simon, 1958), which keeps in consideration all possible end states for which the expected results exceed a specified minimum. An element that they incorporate is that of time - in a sense other than determination of net present value or discounted utility (Prelec and Loewenstein, 1991). The element of time brings into focus the possibility of an environment which changes throughout the planning cycle. Over long planning periods, a stab at gauging the effect of a series of unpredictable future events at the outset is almost always in error.

The Gupta and Rosenhead formulation provides a good basis to begin to look at problems of this nature. There are, however, some significant differences between the simple plant location/distribution problem used as an example in both of their papers, and the complex issues involved in developing space launch infrastructure. The major difference is that in the plant location problem there is only one uncertain variable (demand) and its effects on the system are straightforward and easily determined. The decision is one dimensional: whether or not to construct the next plant, and if so, where. Uncertainty in the launch infrastructure problem manifests itself in many variables which interact in ways which are anything but straightforward. Another difference is that there is residual value in the system of production plants at any time in the future, even if it should be decided not to implement any further development. The system exhibits "stability." For launch infrastructure development, on the other hand, unforeseen events could conceivably render partially completed capital assets (and those decisions made to create them) valueless. The current state of the U.S. Space Station Freedom program (Lawler, 1993) provides a vivid example of this situation. Even though little hardware was produced, the changes in government policy regarding funding and mission relegated much of the investment in scrapped designs to be considered as sunk costs, with little residual value.

These particular authors (Gupta, et al.) seem to have foregone any further investigation along these lines. No further discussion is evident in any available subsequent literature. Others (Friend and Jessop, 1977) have used the analysis of robustness of "action sets" as a method of selecting immediate commitments in the continuing process of suburban planning. Dixit and Pindyck (1995) discuss these same issues, likening the capital investment decision to financial call options, providing the decision maker the right, but not the obligation to purchase an asset at some future time. They go on to say, as do the others, that keeping one's options open is the best hedge against uncertainty. These writings have not, however, added anything of significance to the theory supporting decision making of the nature investigated herein.

Forecasting

Whenever a decision must be made, the consequences of which are dependent on future events which cannot be responded to rapidly, it is implied that some kind of forecasting must be done. It is obvious that forecasting is a constituent element of the research performed herein. Allaire and Firsirotu (1989) have said that, for organizations, predicting the future is essential but not sufficient, because of the inherent uncertainty. Rather, organizations should attempt to proactively shape the future environment (a "power response") and build adaptiveness into their structures.

There is a great deal of literature regarding various theories and methodologies for forecasting, almost all of which, according to Armstrong (1985), has been generated since 1960. The field can be narrowed somewhat for this research because of the type of decision environment considered (long-range, large-scale investment decisions in complex, nonlinear environment with primary uncertainty relating to the decision variables).

The difficulty in forecasting varies directly with the range of the forecast and the number and unpredictability of the factors which influence the decision. Armstrong (1985) defines long range as the length of time in which large changes in the environment may occur. Wittrock (1979) contends that in forecasting, "long range" implies that commitments and restrictions which apply in the present will not necessarily apply over the forecast time span. Relationships between the basic variables which determine current system behavior may not remain the same. In environments similar to those under examination herein, it is this inability to extrapolate the relationships among variables over lengthy time periods, or even to quantify them in the present, which has made forecasting a difficult and imprecise undertaking. Given that this research deals with programs that could take up to twenty years to implement, and that in this amount of time significant environmental changes can occur, treating the forecasting elements as "long range" is appropriate.

Wittrock goes on to say that in cross-sectoral and cross-disciplinary long range forecasting, which are also characteristic of the environment under consideration, alternatives cannot be assigned numerical probabilities. Handling of this kind of uncertainty by planning and policy making organized by industrial sector will not encounter a great degree of success. Armstrong and Raiffa (1968) contend that when there is a high degree of uncertainty and aggregation required for prediction, the ability to forecast is enhanced by decomposing the issue into more manageable subsets.

Armstrong believes that an "eclectic" approach (use of several instruments and techniques to approach the problem from different perspectives) is best when dealing with high uncertainty and "fuzzy" parameters which defy measurement. He presents a taxonomy of forecasting methodologies which is shown here as Figure 2-2.

Of interest here is the differentiation between the "naive" and "causal" methodologies of forecasting. Naive methods simply trace the changes, over time, in the variable to be forecast. Causal methods, on the other hand, investigate the causal relationships between the forecast variable and other variables/factors which influence it in some fashion.

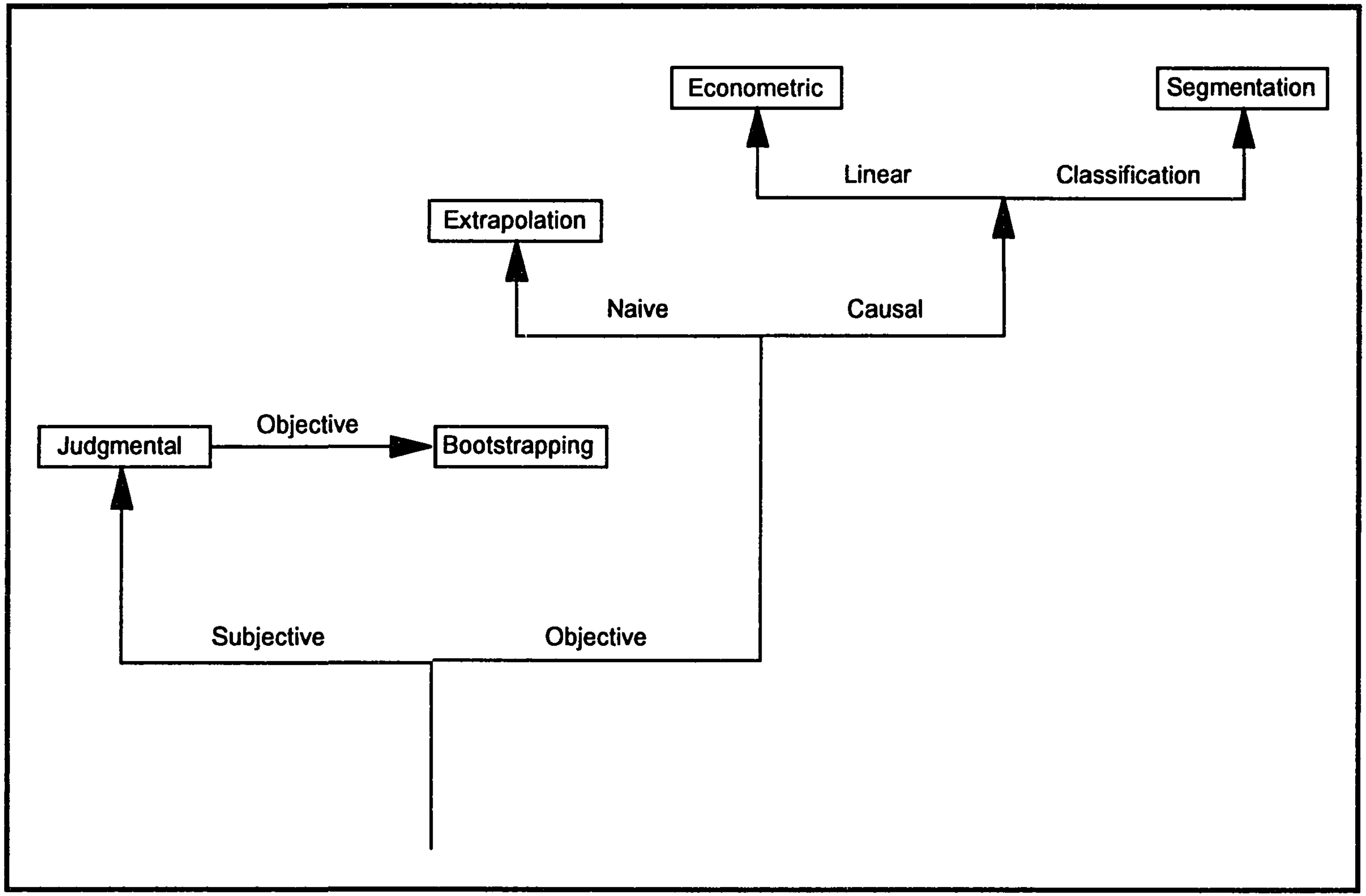


Figure 2-2. Taxonomy of Forecasting Methodologies (Armstrong)

Also of interest is the differentiation between "subjective" and "objective" methodologies. The critical difference is that the objective methods rely more on hard data and are, for the most part, experimentally repeatable, while the subjective methods, although often supported by objective data, are cognitive and heuristic in nature, usually varying between forecasters.

Perhaps the most popular of the subjective methodologies is scenario building, in which alternative futures are generated under various assumptions about intervening events. Armstrong does not recommend scenarios as a way to improve forecast accuracy, but does see them as useful in helping people to confront unpleasant forecasts. Others (Mendell, 1985, Ascher and Overholt, 1983) see scenario building as the most useful non-extrapolative methodology. Mendell feels that the most useful outcome of this kind of exercise is that it enriches the supply of ideas about the future.

Ascher and Overholt feel that whenever there is a richness of interaction, contextual and scenario analyses are the methodologies of choice. If a strategy is designed for each potential environment, then the policy maker can quickly shift in response to changes in the environment. They also contend that there is a "core environment" which is unlikely to change regardless of future events.

One scenario approach which Armstrong supports as a way to help forecasters free themselves of constraints is to envision living in an "ideal" future, and looking back to construct the series of events which transpired to make it so. Priesmeyer (1992) describes this as "visioning." Ascher and Overholt refer to it as "reverse scenario building." Mendell calls it "future backward" scenario generation. The shortcoming of this approach, of course, is that it assumes that the forecasting entity can, in some measure, influence all of the environmental factors which determine its future.

Chaos Theory and Nonlinear Dynamics

Chaos Theory was popularized in the scientific community by Ilya Prigogine (Prigogine and Stengers, 1984), James Gleick (1988) and others, and to the general public by Michael Crichton (1990). One of the basic premises, as discussed by Prigogine and Gleick, is that systems whose behavior appears to be unpredictable or chaotic at one level of investigation may conform to certain behavioral constraints when viewed from a different level. These constraints, or "attractors," confine the possible excursions of the system's behavior to an observable state space, and add an element of predictability to that behavior. It is this element of Chaos Theory which is generic to the analysis and results of the research described herein. Another important characteristic of chaotic systems is their sensitivity to initial conditions: the state of the system at any given time in the future can vary drastically with minute differences in the initial values of parameters. While the system may be predictable over a short time period, longer term predictability (of exactly which state the system will be in at a given time) is not possible. Also noted by these researchers is that chaotic systems are not random. It would not be possible to extract any information from a system which behaves randomly. The only predictability regarding its state at a given time in the future would be that it could assume any of its possible states (the number of which, in a complex system, is very large and probably unknown) with equal probability.

Several researchers have used chaos and nonlinear dynamics approaches as a framework for discussing and investigating economic and organizational phenomena and practices. At a broad macroscopic level, Bullard and Butler (1993) discuss the possibility that economic time series are characterized by chaotic dynamics, and that linear frameworks of analysis can lead to erroneous policy inferences. Nonlinear dynamics gives economists a way to look at systems in which the steady state is unstable, but constrained in some way to a periodicity, or at least bounded by some attractor. They conclude that strange attractors, although difficult to identify without large sample sizes, might be exploited by economists in some situations. They report, however, that the theory and methodologies of nonlinear dynamics had not, at the time of their writing, caused any changes in economic policy development. The same general conclusion was reached by Sayers (1991); that is, that nonlinear structures are observable in financial and economic time series, but their importance in modeling, forecasting and policy formulation is yet to be determined.

Smilor and Feeser (1991) have attempted to analyze the entrepreneurial process of starting up a technology enterprise, using chaos theory as a framework. Their contention is that the process is turbulent (chaotic) and highly sensitive to the initial conditions in the availability and quality of talent, technology, capital and know-how. Chaos theory, then, helps to explain the nature of the risk involved in entrepreneurial ventures, and provides a framework for further research.

Cartwright (1991) uses chaos theory as a framework to discuss planning in unpredictable environments. The systems are considered chaotic because of the element of free will, which renders planning based on prediction illogical. The implication of this with respect to planning is that planners must work with an "ensemble" of forecasts, since any imprecision in measurement of initial (current) conditions, even if the parametric relationships of the predictive model are accurate, will result in a broad range of potential "futures." Planners must learn to work with models that exhibit this kind of behavior, and not fear reliance on simple models of complex behavior. He contends further that since chaotic systems are relatively predictable on a short-term basis, it justifies planning strategies that are incremental and adaptive, rather than comprehensive. Very little empirical work has been accomplished, however, with respect to this theoretical approach to planning.

Relating to strategic development of organizations, Stacey (1993) maintains that managers cannot mandate the long-term direction of their organizations because the nonlinear dynamic feedback of human interactions is unpredictable. Alternatively, what they should do is to create the unstable conditions that allow organizations to redefine themselves in new strategic directions. These strategies emerge spontaneously from chaos through real-time learning and self organizing. Decision making then becomes an exploratory process based on reasoning and analogy rather than analysis of hard data.

Richards (1990) presents some empirical evidence that political strategic decision making can exhibit chaotic behavior, but acknowledges that to identify chaotic behavior in this arena requires representation of decision making in a quantitative schema, and also requires a lengthy series of precise data, neither of which is easily obtained. From her example of crisis decision making, she concludes that while specific outcomes are impossible to predict, boundaries can be established which surround the set of possible outcomes.

Priesmeyer (1992) and Priesmeyer and Baik (1989) discuss some practical ways of examining complex organizational relationships using marginal performance data and the analysis techniques generic to nonlinear dynamics and chaos theory. The premise is that much of the complex behavior exhibited by organizations emerges from deterministic processes, and that some of the complexity can be stripped away by using those techniques and methods of observation. Two of the characteristics of chaotic systems mentioned earlier (constraint imposed by attractors and sensitivity to initial conditions) are central to this analysis methodology, which seeks to reduce the variety in the environment by being able to understand what the system cannot do (or at least is unlikely to do).

Priesmeyer discusses application of this methodology based on chaos theory to forecasting and decision making in the business environment. He uses readily accessible and measurable historical business data such as sales volume and profit as the observed parameters. From this data, he creates trajectories in phase planes, which define the domains of system behavior. Each axis of a phase plane represents changes in one of the parameters over a unit of time. Analysis of these trajectories provides information regarding repeatability and/or domains of the dynamic relationships between the observed parameters.

In Priesmeyer's framework, forecasting is discussed as "visioning," which is similar in purpose to scenario building. The forecaster traces the trajectory of the selected performance parameters throughout recent history and "selects" a desired and reasonably attainable future trajectory. Then the business, assuming that it has some control over its environment, takes such actions deemed necessary to enable the envisioned future.

Departure From Existing Theory

Chaos theory and nonlinear dynamics approaches to forecasting and decision making, as presented by Priesmeyer, have been based on analysis of two variable systems using quantitative data from individual organizations. The decision environment to be examined herein is not well bounded (like an organization) and has many factors which all interact dynamically in ways which are impossible to fully understand and predict. Further, due to the size and complexity of the decision environment, identification of the complete set of factors capable of affecting the decision environment is difficult, if not impossible. The factors are largely qualitative in nature, with little statistical data available. What sets this research apart from prior applications of chaos theory and nonlinear dynamics to forecasting and decision making problems, then, is that it will deal with multivariate systems, using qualitative data as input.

In terms of Armstrong's taxonomy of forecasting methodologies (Figure 2-2), the methodology developed herein is a new approach in which the process is largely objective, but has a distinct judgmental element. The method is primarily causal in that it bases its predictive power on the dynamic relationships between variables. It does not fit in either the linear or classification model, but stands on its own. A modified Figure 2-2 appears as Figure 2-3.

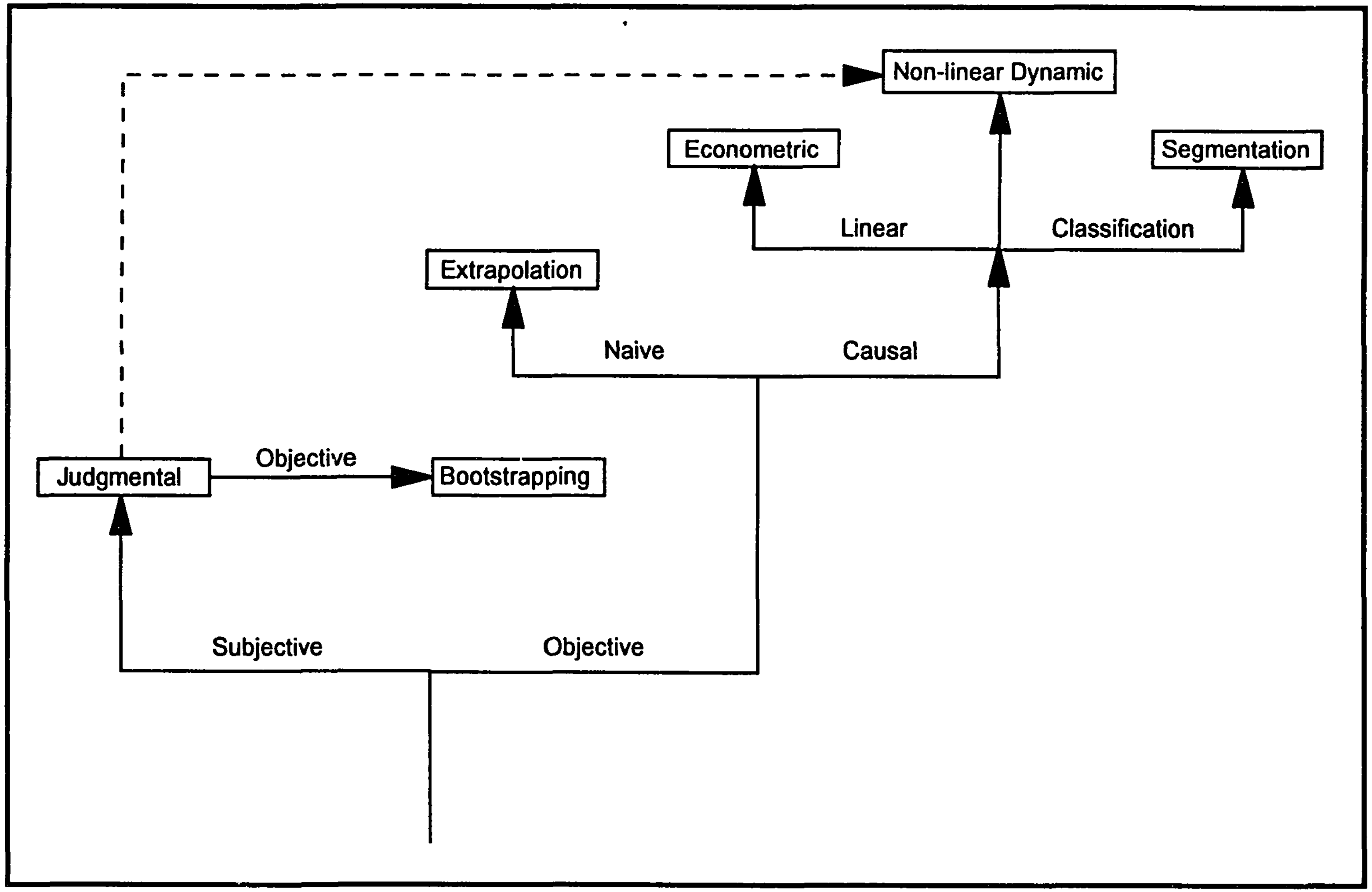


Figure 2-3. Forecasting Taxonomy Showing New Methodology

CHAPTER 3

METHODOLOGY

Background

Data which supports this research was collected over a period of three years. For the first two of those years, data was obtained via literature review and informal contact with people functioning in the selected "environment" (the business of accessing space). This process served to define that environment in terms of its key participant groups and factors that affect the decision process investigated herein. This information was used as a basis for developing the formal data gathering instrument and identifying potential respondents. The reliability and validity of these data are established mainly through the multiplicity of sources from which they were obtained, and the general consensus on those data elements to be identified in subsequent paragraphs, which were used in the investigation.

The Center for Commercial Space Infrastructure (CCSI) was established within the Department of Engineering Management at Old Dominion University in March of 1992. Its stated objective was to foster, through research, development and education, the growth of those technological systems and organizational entities required for commercial space activities. As Assistant Director of CCSI, the thrust of the researcher's activities for the first two years involved definition of the organizational elements of the infrastructure which supports access to space, and gaining entry into those organizations to develop funded research opportunities. Bootstrapping this operation involved content analysis of publications and documents, and personal contact by phone and/or mail with functionaries in industry, government and academia. Appendix A contains a partial listing of the literature reviewed and contacts established as a part of this effort.

Subsequent to that period of bootstrapping, the efforts of the Center were concentrated on establishing the physical assets and management interfaces required to support viable commercial space launch operations at the National Aeronautics and Space Administration (NASA) Wallops Flight Facility at Wallops Island, Virginia. These activities provided the background, much of the specific data and the personal contacts necessary to accomplish this research. The industry and government policy makers involved have been grappling with the kind of decision that is being investigated herein.

Theoretical/Conceptual Framework of the Research

The primary purpose of this research is to introduce and investigate an alternative way of viewing and developing planning strategies in an environment of economic, technological and political uncertainty. It is intended to contribute to knowledge and theory in the area of sociotechnical decision making and policy formulation in any endeavor that involves commitment of resources, over long periods, in unpredictable environments.

Due to the nature of the problem, the research will embody the methodology of Qualitative Inquiry (Patton, 1990). There are several aspects of the research which support this approach. It is basically a process study, seeking to understand and improve the processes of planning and decision making. It involves futuring applications - forecasting and construction of scenarios as predictive tools. It is, to a great extent, exploratory in nature, and the literature review failed to identify any acceptable, valid, reliable quantitative measures or methods that could address the issues at hand. The data required are of a highly subjective nature and not readily quantifiable. While ordinal scaling is performed and the data are mathematically manipulated, the numbers generated are symbolic and merely facilitate the acquisition and presentation of data, rather than their analysis or implementation. The primary data gathering instrument elicits qualitative responses to specific issues, for most of which there exists no hard data.

The research is characterized as Exploratory Applied Research. It is Applied Research, since it seeks to "inform action, enhance decision making, and apply knowledge to solve human and societal problems" (Patton, 1990, p. 12). Applied research takes the findings of basic research and applies them to real-world problems, which is exactly the intent of this research. It is exploratory because it seeks to generate hypotheses regarding the predictability of behavior of highly complex sociotechnical systems in uncertain environments, and identify the direction(s) in which continued research might proceed. The environment under consideration is characterized by emerging technology and (relatively) rapid changes in the economic and political environment. The techniques investigated herein are intended to support decisions and policy formulation, the ramifications of which will not be fully realized for several years. There is, therefore, no practical way to "test" the validity of these measures by monitoring results.

The theoretical perspective of the research is grounded in systems theory, which seeks to determine why a system as a whole behaves as it does, and in the nonlinear dynamics elements of chaos theory. In order to attempt to reconcile some of the uncertainty in the decision process, the policy maker and the environment in which the resultant policy decisions play out must be considered as a system with highly complex and nonlinear interactions.

Identification of Sectors of the Environment

In order to investigate the dynamic relationships in a system, it is first necessary to define the boundaries of that system. The system has been defined so far as including the decision/policy maker and the "environment" in which the decisions must play out. Identification of the components, or sectors, of that environment is necessary not only to bound the system under consideration, but also to provide a framework for selection of potential respondents for data collection.

The system has previously been described in another way: as the infrastructure which supports commercial space launches. The documentation and personal contacts listed in Appendix A provided the data used to develop Figure 3-1. Each major branch of the diagram is operationally defined as a sector of the environment for this research. In a more general sense, a sector of the environment is operationally defined as a group of people or organizations representing a specific discipline, industry component or public agency type which, by some current or future action (or lack thereof) of its constituents, can influence the outcome of strategic decisions. The sectors identified for this research are discussed briefly in the following paragraphs.

NASA performs or directly funds a large portion of the research and development regarding space transportation. They also are responsible for

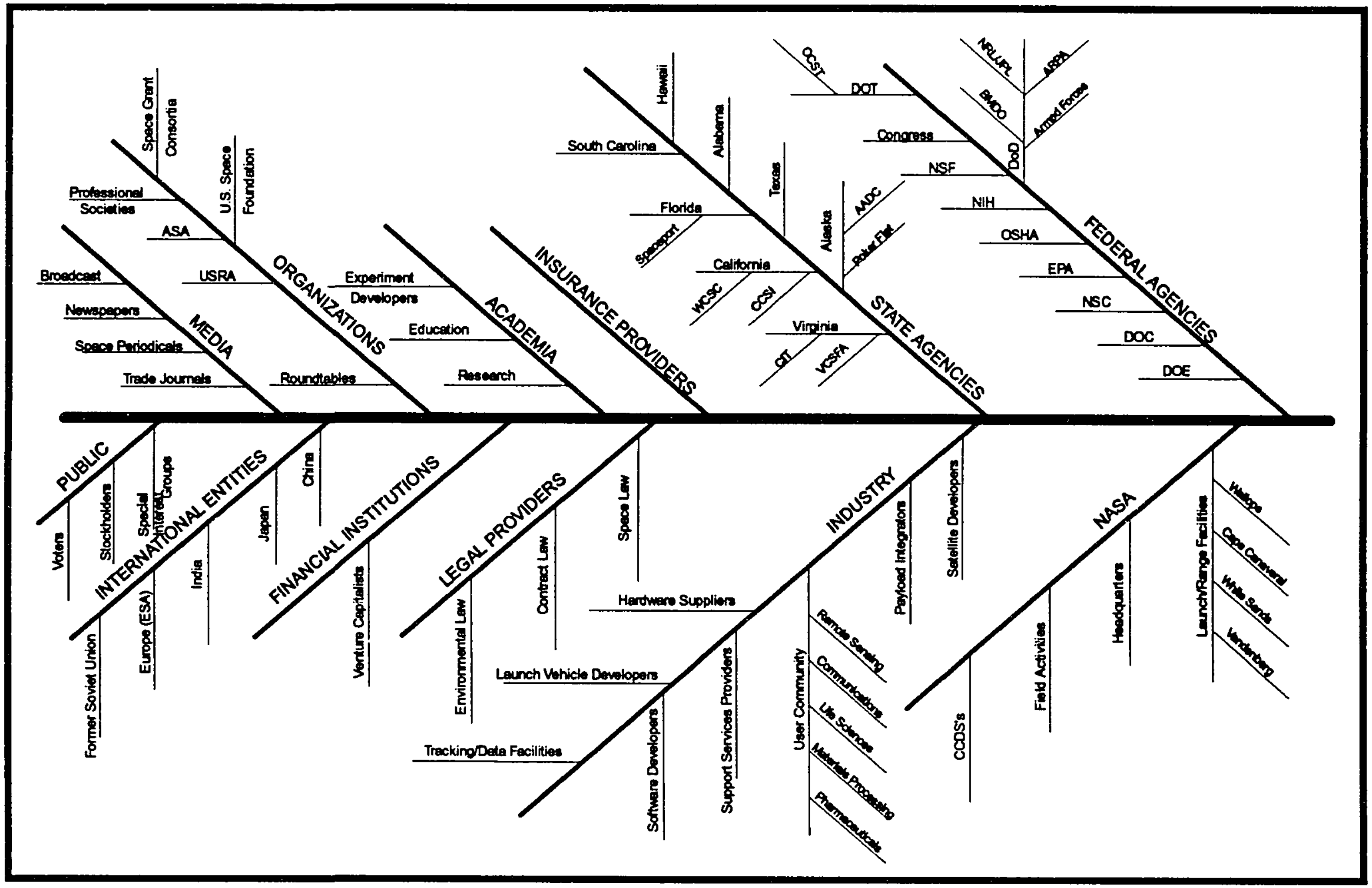


Figure 3-1. Sectors of the Environment

developing many scientific satellites and payloads. But most importantly, NASA is a key player in the "business" of space access.

Agencies of the federal government constitute a significant portion of the infrastructure which supports commercial space access. The Department of Defense (DoD) is the other key player, from the public sector, in the business of space access. DoD (particularly the Air Force) is responsible for conducting much of the launch activity in the U.S., as well as sponsoring a large portion of the research and development. Federal agencies are also largely responsible for setting the tone of the regulatory environment, which can be looked at as either facilitating or constraining space access. The Department of Transportation is responsible for granting licenses and defining insurance guidelines for commercial launch vehicles and activities. Other agencies sponsor basic research and are involved in payload development. And Congress, of course, is responsible for legislation which affects the conduct of space business.

State agencies are becoming involved, to an increasing extent, in the business of space flight. All of the states shown in Figure 3-1 have pursued some plans to provide a launch facility. Alaska, California, New Mexico, Florida and Virginia all currently have state-sponsored "spaceport" activities which currently, or will in the near future, have launch capability.

The commercial space industry, of course, is the provider of the majority of space hardware and support services (whether privately funded or under government contract). Industry is also the driving force behind commercial space, in that it determines the need, markets the customers and designs the systems that satisfy that need. Because industry is profit motivated, it also provides the impetus for cost accountability and effectiveness in space operations.

Insurance providers play a significant role in determining the cost of space access. Satellites and payloads are routinely insured against loss or damage before, during and subsequent to launching. Third party liability insurance against possible loss as a result of the act of launching vehicles is also required.

The legal aspects of the space business are complex and, in many areas, still being defined. Space law is becoming a specialty among legal practitioners. Legal interpretation of various aspects of space enterprise, in addition to being a cost element for providers, has an effect on the laws which define the business environment.

The academic community provides basic and applied research which contributes to the body of knowledge in all of the technology and operations domains. Many academic institutions, either individually or cooperatively, through consortia and associations, develop scientific experiment payloads and satellites. Perhaps most importantly, academia produces the scientists, engineers, technicians, managers and business people who populate the space infrastructure.

One of the more serious problems for space business ventures is securing the large amounts of capital necessary to underwrite spaceborne system and launch vehicle development programs. The return on investment usually takes many years to materialize, and is (as this investigation tends to support) risky. This kind of environment makes the financial industry, and the financial decision makers in major corporations, an important sector of the infrastructure.

Space-related organizations provide important forums for communications regarding business and technology issues. Some have powerful lobbyists which can influence high level policy. Others organize efforts of industry, government and academia in pursuit of joint space ventures.

International entities play an important role in the infrastructure, mainly by way of providing competition to U.S. systems and service providers. In the launch services segment of the industry, the competition is especially fierce, due to heavy foreign government subsidization of launch vehicle providers. International organizations also control the availability of the radio frequency spectrum available to proposed communications systems.

The media plays an important role in disseminating technological and business information, and also influences public perception and awareness of space issues. The public at large can hold sway over legislative and business policy via their votes for public office, proxy votes as stockholders in corporations and pressure exerted by special interest groups.

Identification of Factors Affecting Decision Making

The question which provides the arena for the research is whether it is advisable to invest in development of the physical and organizational infrastructure to support commercial access to space. From a business standpoint, the problem would be approached in terms of return on investment, which is dependent on the size of the initial outlay and the amounts and timing of subsequent cash flows. The uncertainty in the environment for the potential investor (that which this research seeks to reduce) manifests itself in terms of those future cash flows.

In order for the research to proceed, then, it was necessary to isolate and operationally define the factors which exert influence over the investment decision (i.e., the potential future cash flows). In general, a decision factor is operationally defined as a discernible policy or activity of any person, group, organization or sector in the environment that has an influence on the outcome of strategic decisions.

For purposes of this study, the ten most relevant factors which emerged from the informal data gathering period were selected. Given the complexity of the environment, it is conceded that there exist several other environmental factors that can be of influence, but considering the exploratory nature of this investigation and its stated objective, investigation of additional, less influential factors is expected to yield diminished returns. By definition, in an environment characterized by "primary" uncertainty, the full set of these factors cannot be defined. Therefore, to require that all factors be identified would defeat the purpose of the methodology.

Even with consideration limited to ten factors, there is substantial richness and depth to the problem. Attempts at construction of an influence diagram (Clemen, 1991) for the factor set were futile: the number of potential influences were more numerous than the permutations of the factors.

Since the data gathered for analysis related directly to the set of factors, it was necessary to operationally define each of them. The following paragraphs provide those definitions and brief discussion of some of the more readily apparent influences.

Arguably the most influential of the factors considered is the market for space launches, which when viewed historically is the level of launch activity. For this study, the market is defined as the number of payloads, in the range of five hundred to eight thousand pounds that have been manifested for launch into low earth orbit. Its relevance to the decision is that the strength of the market (the number of payloads) directly affects the investment risk.

The launch cost, per pound of mass, of placing a payload into low earth orbit using expendable launch vehicles affects the profitability of the payload developers, the ultimate customers for launch services. Reducing the cost of orbital access lowers the threshold of acceptance for payload project budgets, thereby creating a larger market.

The legal and regulatory environment affects the costs and availability of launch services. Environmental laws in the United States effectively limit the number of land-based launch sites to those that currently exist, and also place some constraint on the types of launch vehicles that can be used. Licensing of commercial launches requires conformance to regulatory mandates such as the level of third party liability insurance coverage required, range safety, personnel safety and interference with on-going air and sea transportation activities. This factor is defined in terms of the extent to which the administration is supportive of commercial space activities.

The support of the current federal administration and its policy regarding commercial space has a distinct effect on the way in which commercial entities interact with federal agencies. Aside from NASA, which is treated separately, agencies such as the Department of Transportation, Department of Commerce and the Environmental Protection Agency play important roles in the facilitation of commercial space access. The administration is also influential in establishing national policy in many areas which affect the ability of space enterprises to compete, both domestically and internationally. This factor is defined in terms of the extent to which the administration is supportive of commercial space activities.

The amount of competition, defined as the number of competing entities offering launch services in the payload range of interest is a determining factor of market share and profitability. Competition from foreign providers who are substantially underwritten by their governments, is particularly challenging for U.S. launch companies.

The introduction of new technology affects both the cost of space access and the potential for exploiting the environment of space for commercial and scientific endeavors. Technology, in effect, provides the "reason to go" into space, as well as the means to get there. In terms of this investigation, the most predominant of these technologies are communications, launch vehicle design, propulsion, remote sensing, materials processing and life sciences. This factor is operationally defined as the aggregate rate of new technology introduction, without segregating it into specific technologies.

Public opinion regarding space exploration influences Congress in its legislative actions (especially concerning budgets), influences corporate decisions via stockholder influence, and influences the number and quality of people who are interested in pursuing education and careers in space related occupations. Special interest groups can also influence government actions at the grass roots level. This factor is defined in terms of the extent to which public opinion is supportive of space activities.

The amount of applied academic research performed on space related issues and problems directly affects the rate of new technology development and application. It also affects the number and quality of potential workers in the industry, particularly if performed at academic institutions. This factor is defined in terms of the level of space-related academic research.

At the time of this writing, three of the four operational space launch facilities in the U.S. are owned by the Department of Defense (Cape Canaveral and Vandenberg by the Air Force and White Sands by the Army). The support of DoD , and its policy toward private sector activities, therefore, has a marked effect on the viability of commercial space activities, due to its influence on cost and scheduling of launch activities. This factor is defined in terms of the extent to which DoD is supportive of commercial space activities.

The fourth operational launch facility is owned by NASA. The effects on commercial space operations, then, are the same as those of DoD. The support of NASA, and its policy regarding technology transfer and cooperation with commercial enterprises also has a direct effect on the viability of commercial activities. This factor is defined in terms of the extent to which NASA is supportive of commercial space activities.

The preceding discussion highlights a few of the major interactions that are assumed to exist between the factors. There are certainly many more subtle but still potent interactions that exist. It is easy to see how difficult it would be to identify the individual effects of all the potential interactions, even if they were linear and static. Since they are nonlinear and dynamic, direct analysis and prediction by mathematical or traditional simulation techniques becomes impossible. This gives some insight into the nature and magnitude of the uncertainty in the decision environment.

As stated earlier, there is no way to identify all of the factors which might influence the decision. For the methodology to be useful in a practical situation, however, it is important that as many of the major influences as possible be identified and included in the analysis. This brings up an important issue regarding the generalizability of this methodology to other decision systems. In this research, the researcher was also a domain expert, and this expertise (based on knowledge of the environment gleaned from experience and literature content analysis in the informal data gathering phase) enabled "direct" identification of the environmental sectors and decision factors. It cannot be assumed that a researcher in another decision system would have the requisite expertise to perform that dual role.

To generalize the methodology, identification of the infrastructure sectors and decision factors must be undertaken as part of the formal data gathering process. The additional procedural steps required will be discussed subsequently in this chapter, in the section entitled "Selection and Recruitment of Survey Respondents."

Formal Data Gathering

Human Subjects

In this research, human subjects were used as sources of data. The sections to follow discuss the survey instrument and the process of selecting and recruiting respondents.

Participation by respondents was on a strictly voluntary basis, and the survey instrument was completed at their leisure. Potential respondents were contacted by phone and briefed regarding the process prior to agreeing to participate. There was no organizational participation: only individuals were solicited. No one from the researcher's organization was solicited for data gathering. There was, therefore, no pressure from within an organization to participate, and no consequence of not participating. Anonymity of respondents was guaranteed, and maintained throughout the process. In this document, they are referred to by coded numbers, and any references to themselves in the data were stricken.

This process was designed with two objectives in mind: the first being to avoid, as much as possible, exposing the respondents to any potential hardship, and the second was to reduce the possibility of any bias being introduced by the relationship between the researcher and respondents. All data were collected in the absence of real-time contact between researcher and respondent.

Human subjects were also used, subsequently, to support the analysis of data. In this instance, the subjects were chosen at random from the researcher's organization. The objective was to preclude researcher bias in the interpretation of data, and the only requirement for participation was that the subject be unfamiliar with the factors being analyzed. Again, participation was strictly voluntary and anonymous. The relationship between the researcher and subjects was collegial: none reported to the researcher organizationally. The task was simple, involved little time, and was done at their leisure and not in the presence of the researcher.

The Survey Instrument

One of the aspects which makes decisions difficult in environments of primary uncertainty and nonlinear dynamics is that relevant and meaningful quantitative data which directly measures the "amounts" of the factors is not readily obtainable. Such is the case for the decision environment under investigation. Of the ten factors identified above, only market, cost and competition lend themselves to any kind of direct measurement. A method was required to collect qualitative data that embodies the kind of information desired: relative levels of factors from one period of observation to the next. The resulting qualitative instrument was employed for all factors, including those for which quantitative data may exist.

When dealing with very large decision scenarios, the level of people involved tends to be rather high. The target respondent sample population included people with oversight responsibilities (program managers, department heads, high level staffers, etc.). Given the constraints on their time, and perhaps lower level of technical sophistication, the instrument needed to provide an interface that would be readily understandable and somewhat familiar, facilitate the desired data format, and be doable in a reasonable amount of time or in multiple, short sessions. Because of the geographic dispersion of the desired sample group, face-to-face contact for data gathering was not feasible.

Given those requirements and constraints, the survey instrument was designed so that it could be self-administered and would operate in a familiar environment - a personal computer using Microsoft Windows™. To facilitate the gathering of data which highlights changes in levels or amounts of the factors from respondents who would not be expected to have hard data, an input scheme was devised, using the graphics user interface of the computer. Data is entered using the computer's mouse to create a set of bar graphs which illustrate the respondent's knowledge of the historical behavior of factors related to the decision at hand.

Each of the ten factors discussed above is the subject of a bar graph and has a dedicated data entry screen and data area in the software. The question posed for each factor requires the respondent to relate his or her knowledge of how the factor has changed over the past decade. The question set is reproduced here as Table 3-1. Each bar of a graph corresponds to the relative "amount" of the factor under consideration, on a ratio measurement scale (Kerlinger, 1986) of zero to ten, for a given year. The independent variable of the graph (time) is divided into ten years, ranging from 1985 through 1994.

TABLE 3-1

SURVEY QUESTION SET

Question 1	What has been the relative level of small to mid-sized (500 to 8,000 lbs. to LEO) launch activity over the past 10 years?
Question 2	How has the cost per pound of payload mass to LEO, for Expendable Launch Vehicles, varied over the past 10 years?
Question 3	How strongly has the legal/regulatory environment supported commercial space activities over the past 10 years?
Question 4	How strongly has the federal administration supported commercial space activities over the past 10 years?
Question 5	What has been the relative level of competition (how many small to mid-sized launch providers, world-wide) over the past 10 years?
Question 6	What has been the relative level of new technology introduction for small to mid-sized ELV's and satellites over the past 10 years?
Question 7	How supportive of space activities has the public been over the past 10 years?
Question 8	What has been the relative level of space-related academic research activity over the past 10 years?
Question 9	How has NASA's support of commercial space varied over the past 10 years?
Question 10	How has DoD's support of commercial space varied over the past 10 years?

To anchor the data in time, and to support its validity, respondents are requested to identify, where possible, specific events which are reflected in significant features of the graphs (maxima, minima, points of inflection). The reliability of the data, in terms of repeatability, is not considered important here. Repeatability in terms of the same respondent duplicating data levels at each interval on successive test runs is not important because it is the relative changes and trends in the data which are being observed, rather than the absolute levels. Inter-respondent repeatability of incremental data was not anticipated and not required, since analysis was based on aggregation of these data into average responses. Reliability in terms of accuracy is not measurable for most of the factors, since the data are qualitative and there is no standard against which to measure. Respondents were, however, free to use, and specifically asked to identify, the sources of any quantitative data used in their responses.

To further support the data validity, there are opportunities associated with every data entry screen for respondents to provide additional information and comments, in text format. There is also a final summary comments screen to provide space for general comments regarding the survey topics or the instrument itself.

To provide the easiest path of data input and retrieval, the instrument was developed in Microsoft Visual Basic™ and is linked to a Microsoft Access™ data base. The software was compiled to an executable code that installs and runs under Microsoft Windows™ and is distributed on floppy diskettes. Respondents were required to run the software program and return the diskettes to the researcher when finished. Appendix B provides a complete set of the software "screens" as they appear to the respondent, and a copy of the instructions for use which accompanied each diskette.

Selection and Recruitment of Survey Respondents

The objectives of this phase of the study were twofold. The first was to ensure that there was a sufficient number of responses to each question to yield a data sample size sufficient to apply some statistical techniques to evaluate the data, and to provide some confidence in using the average response as data for the analysis. The target, given the limitations of resources available and the expected inability of respondents to address all of the ten questions posed, was to obtain a minimum of five responses to each question.

The qualifications for respondents required that they be rather intimately involved, in a decision making position, in their specific infrastructure sector. They would also possess experience and/or knowledge of the environment that extends over the past decade. This kind of respondent demographic ruled out a random sampling scheme. A purposeful sampling scheme (Patton, 1990) was implemented to achieve the objective.

The second objective was to maximize the breadth of responses over the various sectors of the infrastructure. A maximum variation sampling scheme (Patton, 1990) was adopted. While this sampling scheme is more likely to induce apparent randomness in the responses, it serves to highlight those particularly significant patterns which emerge from a diverse respondent group. The target was to have at least one respondent from each of the infrastructure sectors (with the exception of the general public and international entities).

In order to ensure that the minimum of five responses would be obtained for each question, a total of twenty potential respondents were solicited. To maximize the potential number of qualified responses per respondent, a selection process was devised using the principles of Quality Function Deployment (QFD) as described by Bossert (1991). QFD is a quality tool that establishes the framework for articulating exactly what an organization needs to do to respond to customer requirements. The mechanism is a set of correlation matrices which, at the lowest level, relate the "whats" (customer requirements) to the "hows" (organizational responses). The magnitudes of the correlations, expressed numerically in the matrix cells, indicate the leverage of the organizational responses in satisfying customer requirements.

The correlation matrix shown in Figure 3-2 was developed, relating the infrastructure sectors to the decision factors. The correlations indicated in the matrix cells were developed by the researcher, based on information obtained

Environmental Sectors \ Decision Factors	Launch Activity	Launch Costs	Regulatory Env.	Political Support	Competition	Technology	Public Opinion	Academic Actitity	NASA Support	DoD Support
NASA	3	3	3	9	3	9	1	3	9	3
Federal Agencies	9	3	9	9	3	1	3	1	1	9
Space Industry	9	9	3	3	9	9	1	1	9	3
State Agencies	3	3	3	1	1			3	1	1
Legal Providers	1		9	1						
Financial Providers	3	9	1		1	1				
Academia						3		9		
Media	3	1	1	3	1	3	3	1	3	3
Associations/Orgs	1	1	1	3	3	3	3	1	3	3
Insurance Providers	3	3	3			1				

Key: 1 = mild correlation, 3 = moderate correlation, 9 = strong correlation

Figure 3-2. Correlation Matrix - Decision Factors to Environmental Sectors during the informal data gathering phase, and represent the expected ability of a person in a particular sector to be knowledgeable regarding the associated factor. The number of respondents to be solicited from each sector was determined by multiplying the weighted average of the correlation scores for each sector (row in the matrix) by the desired number of respondents (twenty).

In order to further encourage diversity of respondent viewpoints, whenever more than one respondent was to be solicited from a sector, they would be selected, where possible, from different subgroups as shown on Figure 3-1. Once the sector subgroups were identified, contact was established via telephone with individuals meeting the experience/knowledge criteria. Those who agreed to participate were provided with the survey instrument. A listing of the positions held by the solicited respondents is provided as Appendix C.

Returning to the issue of generalizing the data gathering process to situations in which the researcher is not also a domain expert, it is evident that some modification to the above methodology would be required. In the case of a "naive" researcher, a two-stage survey of respondents would be necessitated to ensure that all relevant factors and sectors are addressed in the survey process.

It is reasonable to assume that in an organization making strategic decisions of the type addressed, there will be individuals who can formulate a "basic set" of decision factors and environmental sectors, and also identify potential respondents within those sectors. To develop a full spectrum of factors and sectors from this basic set, QFD techniques would again be used. In this case, a matrix with partially completed axes (containing only the basic set of factors and sectors) would be distributed to the limited set of respondents, who would then be asked to complete the matrix and establish the correlations. From the responses, a comprehensive set of factors, and a complete list of sectors from which to draw additional respondent candidates could be generated. Correlation figures would establish the levels of sector representation in the candidate mix, as before.

Data Analysis

Data Processing

The survey software automatically converts the qualitative graphic inputs to numeric variables on the zero to ten ratio scale, and stores the values in a Microsoft Access™ data base file on the survey diskette upon completion of program execution. Data from returned survey responses were compiled in a Microsoft Excel™ spreadsheet. The spreadsheet was used to calculate and plot all parameters and statistics used in the analysis. Quantitative data and comments were also transferred to a Microsoft Word™ file and presented as Appendix D.

Development of Marginal Change Data

The primary characteristic of the data which is examined in this analysis is the relationship of marginal changes, over successive years, between two or more of the environmental "factors" which influence the decision. The analysis evolved through two approaches.

The first approach was to generate the arithmetic mean of the responses for each factor-year (launch costs in 1986, for example). The incremental differences, or "deltas," between successive yearly means were calculated and used as the marginal change data. This approach, however, was seen to have some shortcomings. As anticipated, the small sample size and diversity of respondents gave rise to a substantial sample variance in the raw data for some of the factor-years. The level of variance suggested that the content validity of the data (whether the data were a representative sample of the characteristics of the environment) was an issue to be addressed. (A detailed discussion of the validity issues of the research is contained in Chapter 4). Due to these shortcomings, this approach was abandoned.

In order to address the content validity issue, the second approach was devised. It allowed the ancillary data (identification of related events and additional comments) provided by the respondents to be incorporated into a filtering process which employed a consensus seeking algorithm (described below) and a polling scheme to reinforce a majority opinion regarding the direction of change in the marginal factor-year data.

The approach was implemented by first generating the incremental changes in the factor-year data for each of the respondents, for successive year pairs. Using respondent S-1-1 as an example, the data provided for launch costs in 1992 and 1993 were 5.75 and 6.25, respectively. The incremental change, then, is +0.50, or +5% of full scale. The incremental changes so derived were compared among respondents, and aggregate data points generated based on the following rules for inclusion.

> If 75% or more of the respondents for that factor indicated the same direction of change (positive or negative), a consensus was assumed and those in agreement were used to generate an average. The ancillary data were consulted to see if there existed any factual evidence to overrule the consensus. The ancillary data were also consulted for explanation of any "outliers" (incremental changes that differed from the average by more than 25% of full scale). If the ancillary data conclusively demonstrated that the outlier was a result of faulty interpretation or assumption, it was discarded: otherwise it was retained.
>
> If a 75% consensus was not observed, the ancillary data were consulted to determine if there was conclusive evidence of the direction of change. In the absence of any such evidence, the arithmetic mean of all the incremental changes was used as the data point for that factor-year pair.

The data generated by this second approach were used in the remainder of the analysis.

Development and Analysis of Phase Plane Diagrams

In order to examine the nonlinear dynamic relationships between the factors, it is valuable to plot their trajectories over time. A phase plane diagram, as suggested by Priesmeyer (1992), is constructed by plotting the marginal change data of any two factors on Cartesian coordinates. Figure 3-3 is the phase plane diagram which compares the marginal changes in the "Launch Cost" factor to those of the "Legal/Regulatory Environment" factor. The trajectory of the relationship between these two factors is shown for changes in the year-pairs 1985-1986 through 1993-1994. The arrow represents the direction of time progression. The axis scales are in terms of percentage of full scale change on the ratio measurement scale used in collecting data. Since the factors are all macroscopic in nature, it is assumed that the decision maker has no significant influence over changes in the factor levels. Therefore, there is no designation of independent and dependent variables in the phase plane diagrams. The axes are chosen arbitrarily.

There are several important pieces of information that can be drawn from examination of these diagrams. Those which are generic to this analysis are discussed in the following paragraphs.

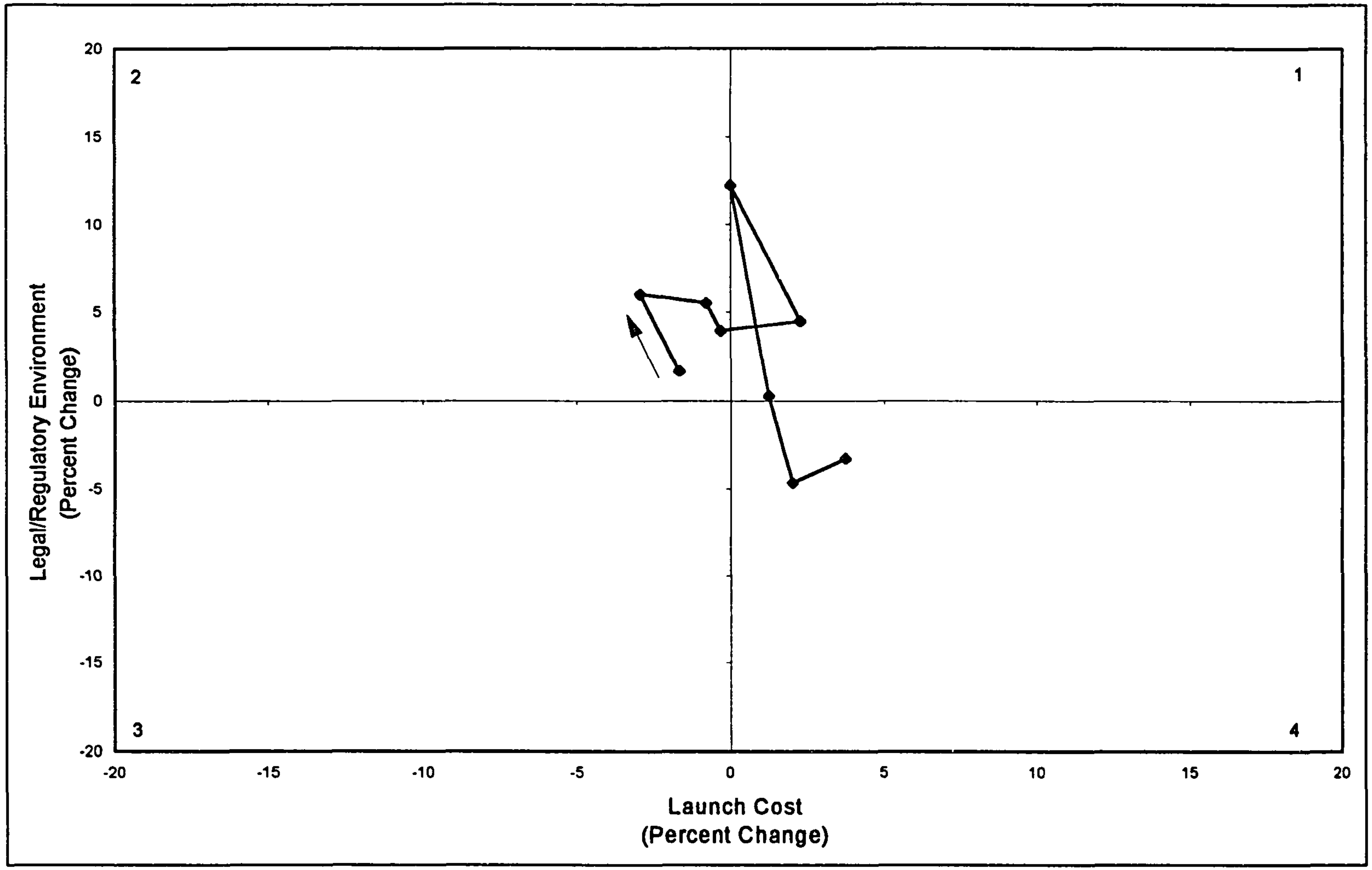


Figure 3-3. Phase Plane : Legal/Regulatory Environment vs. Launch Cost

Periodicity

The phase plane, as is evident in Figure 3-3, is divided into four quadrants, with the Cartesian coordinate origin at their intersection. A data point at the origin would indicate no change in either factor. Points in Quadrant 1 indicate positive changes in both factors, while those in Quadrant 3 indicate negative changes in both factors. Quadrants on the minor axis (Quadrants 2 and 4) indicate positive changes in one factor accompanied in time by negative changes in the other. The visits to these quadrants by the trajectories can indicate some kind of periodicity, which implies some predictability, or a lack of periodicity, which is indicative of a higher order of chaotic behavior and little or no predictability. Priesmeyer uses a method of determining periodicity by observing the four most recent marginal changes. If all four are in the same quadrant, there are no oscillations between the factors and it is identified as a "Period 1" trajectory. If the four observations are confined to two quadrants, a tendency toward a simple, bi-polar oscillation is indicated, and the trajectory is identified as a "Period 2." If all four quadrants are visited, there is a suggestion of oscillation of the two factors at different frequencies (e.g., one may switch sense every year while the other switches every two years). Repeatability of the four quadrant sequence would need to be verified from earlier data to verify this behavior, which is identified as a "Period 4" trajectory. Any trajectories which do not follow such patterns are considered to be in high order chaos and are identified as "Period 8."

All of the factor-pair phase planes were classified in this manner. To evaluate factor-pair relationships for transitions in periodicity (becoming more or less chaotic) the same process was applied to the four data points immediately preceding the final four.

Prior to the foregoing classification of the factor-pair relationships, each of the phase planes were examined qualitatively by the researcher to determine the existence of any pattern in the trajectories which might indicate where the next data point might lie. This was accomplished by observing the trajectory and making a mark on the plot at the location considered most likely for the next data point. Since there was a significant potential for invalid data due to researcher bias (a pre-disposed notion of the factor relationships) in this process, others who were not part of the research and were considered to have little knowledge of the environment in question were enlisted to repeat that analysis. They were told only that it was a time series of data and that their responses should be based on whatever pattern the plot appeared to be generating. Data were recorded from the researcher and four additional "analysis respondents," noting the quadrant of the projected next data point and whether that point was positioned closer to or farther from the origin.

This process of next point prediction might give rise to some questions concerning reliability of the resultant data. How is it possible for someone with no knowledge of the system to accurately predict what it will do next? Priesmeyer (1992) treats this issue in his discussion of visioning as a forecasting and decision making tool. He makes several credible arguments. First, he contends that, since the system is acknowledged to be chaotic, standard objective forecasting models (extrapolation, econometric, segmentation and the like) provide little insight. Secondly, since the complexity precludes exact numerical prediction of behavior, it is more appropriate to observe the dynamic changes in the system as predictors of "realms" of future behavior. Thirdly, that awareness of the identity and values of the factors represented on the axes is not required to obtain meaningful data. The use of the naive analysts herein was prompted by Priesmeyer's method of visioning a future for an organization. He selected his "next point" from a phase plane without paying any attention to the values of the parameters. He describes the process as follows:

> I chose a position that simply looked right - it looked appropriate given the pattern on the screen. It looked consistent and reasonable with the pattern of things. It seems important that the proposed position was chosen without regard to the numbers. It is a future condition that seems consistent with the current state of the system and the apparent forces that control the behavior of the system. (Priesmeyer 1992, 179-180)

The implication is that one need not know (and is perhaps better off not knowing) the nature of the system. All that is required is recognition of a pattern:

something that the human mind is especially well suited to. In the case of the process of generating the next point data herein, it is considered an *advantage* for the analysts to be unaware of the mechanisms of the behavior, in order to preclude the potential of *perceived* causal relationships contaminating the analysis.

This is an important issue when considering the generalizability of the methodology. There is no requirement for researchers to be domain experts in either the decision environment or in the application of nonlinear dynamic systems techniques.

The periodicity and "next-point" projections were used to isolate factor-pair relationships which are most likely to contain information regarding future behavior and present the possibility of inter-factor causal relationships. Each factor was compared with the set of nine remaining factors. In each set, the factor-pairs which exhibited a low periodicity (2 or 1) for the latest four year period, and either decreasing or consistent periodicity over the two four year periods were first isolated. From that group, the single factor-pair which exhibited the lowest and most consistent periodicity and most consistent next point quadrant selection was selected for further analysis. This process yielded one factor-pair for each factor.

Limit Cycles

A limit cycle is the trajectory of the changing relationships between factors as it is plotted on the phase plane. Generally, there are two types of limit cycles of interest here.

In the first, the dynamic relationship remains within an observed region (not necessarily in one quadrant) of the phase plane over the ten year period of observation, reversing its direction whenever it appears to be headed out of the region. Figure 3-3 illustrates such behavior. It is likely that the trajectory is bound to an attractor of some kind. An attractor is some point or set of points (which are not necessarily identifiable) which define a "basin" or domain of behavior from which the system will not stray unless acted on by some external stimulus. Even though the relationship may display high order chaotic behavior, the attractor applies some constraint to the behavior. As related by Ashby: "That something is predictable implies that there exists a constraint" (Ashby 1956, 132). Without any constraint on the system, there would be an infinite variety of possible states, all behavior would be random, and no information would be obtainable. So the existence of an attractor allows some information (in terms of what the trajectory is unlikely to do, more than what it absolutely *will* do) to be imparted.

The second potential kind of behavior involves an "escape" from an attractor due to some external stimulus. Such behavior is illustrated in Figure

3-4. This behavior is the most prominent cause of what has been termed (and identified in the analysis as) Period 1. Even though it may be escaping an attractor, the trajectory, having remained in the same quadrant for at least four consecutive years, is likely to persist in that quadrant unless the changes have been diminishing in magnitude. This too provides some information regarding the relationship between the two factors involved.

The information obtained from the limit cycles was used to support the identification of those relationships most likely to contain information regarding future behavior. The results are discussed in Chapter 4.

Development of System Uncertainty Index

Ashby (1956) defines variety as the quantity of distinguishable elements in a given set or possible states that a system can assume. As discussed in the prior section, for information to be extracted from the system (a reduction in uncertainty), there also must be some constraint, for without constraint all changes of system state would be random. In terms of the factor-pair dynamic behavior examined herein, variety can be considered to be a function of the number of possible states that the two factors might take at any given time. Constraint can be considered to be imposed by the presence of an attractor, which limits the excursions of the dynamic trajectory to a specific realm.

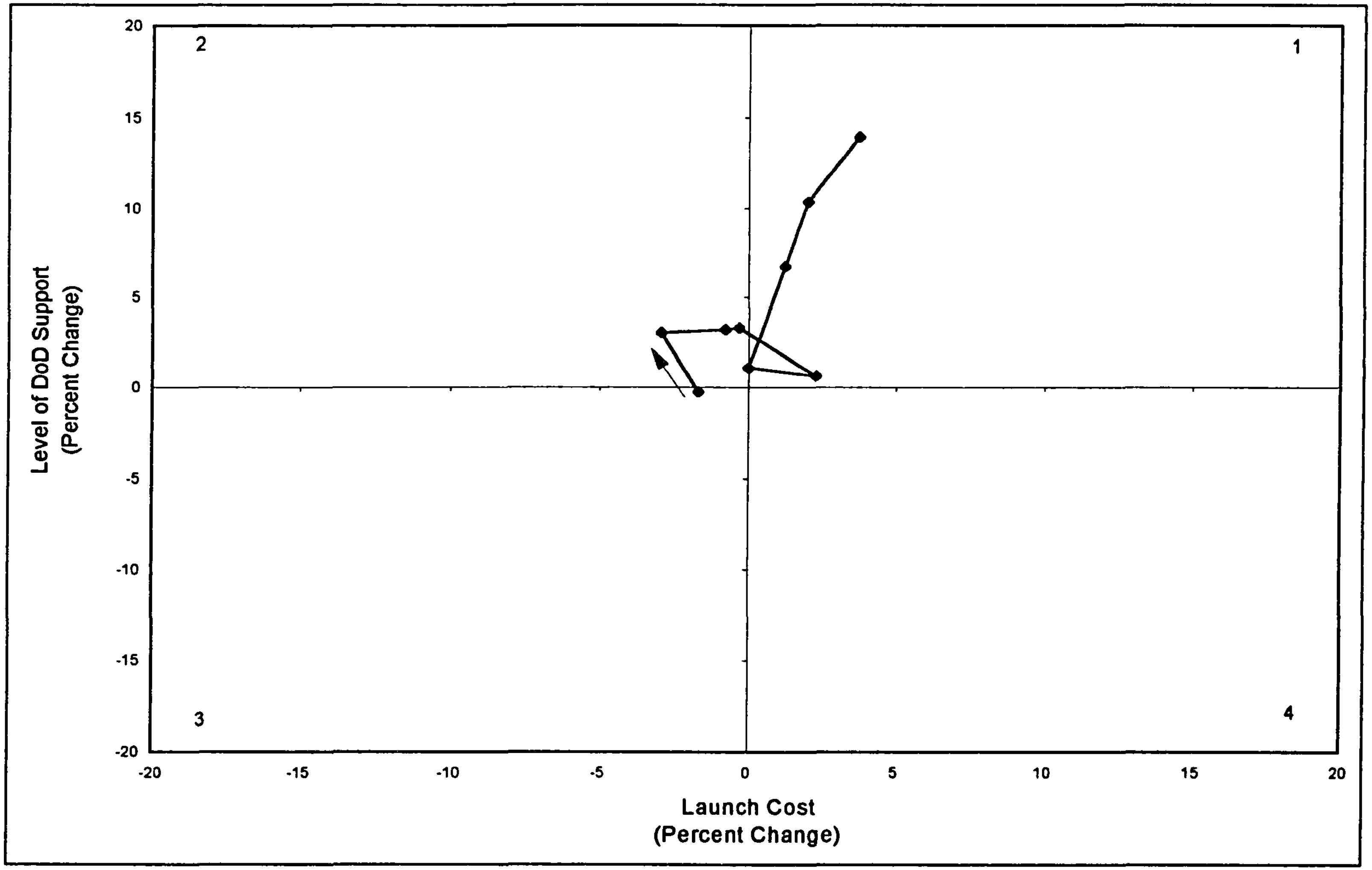


Figure 3-4. Phase Plane: DoD Support vs. Launch Cost

Pursuant to this discussion of variety and constraint, it can be stated that if the system constraints are relaxed and the possible number of states increases, then the uncertainty associated with that system increases. The data used in this analysis is the set of marginal changes between pairs of decision factors. Increasing rates of change, then, with the knowledge that they cannot continue to increase indefinitely, can be said to be indicative of greater variety and/or a relaxation of constraint since, in the phase plane, those conditions would expand the boundaries of a limit cycle, or perhaps escape the current attractor entirely.

On the phase planes, the magnitude of change can be expressed by the magnitude of vectors extending from the origin to the data points, as shown in Figure 3-5. Increasing vector magnitudes, then, will indicate increasing rates of change (and, consequently, increasing uncertainty) relating to the dynamic interaction of the factor-pair.

For this research, the System Uncertainty Index (SUI) is operationally defined as the sum of the absolute values of those vector magnitudes in a given time period (one year, in this study) for the system under investigation. The analysis includes treatment of each factor as related to the remaining nine, and also the entire system of 45 factor-pair interactions.

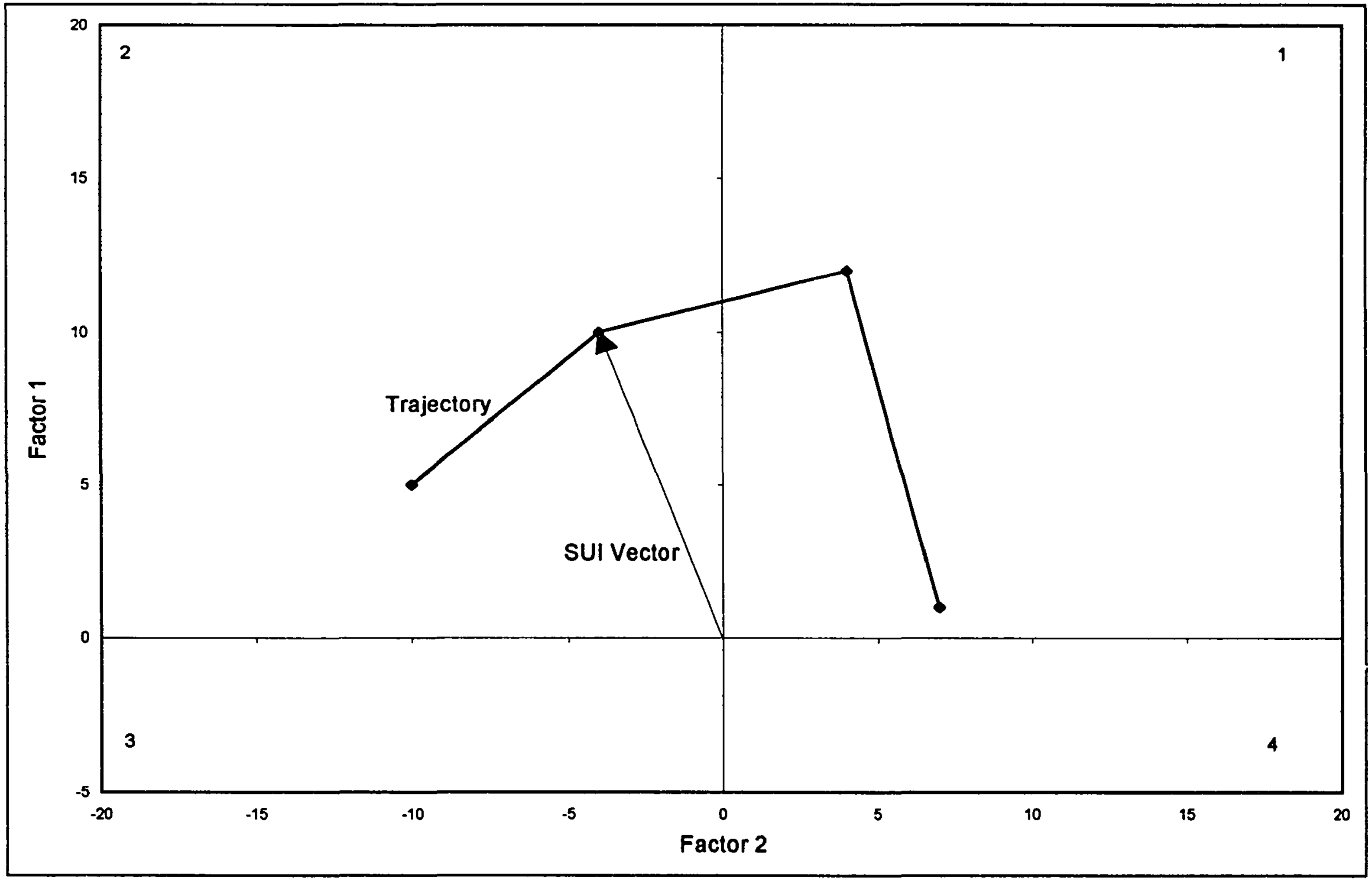


Figure 3-5. Phase Plane Diagram Showing SUI Vector

Summary of Methodological Process

The methodology described in this chapter is considered to be a primary contribution of this research. The technique of identifying and correlating the sectors of the decision environment and the factors affecting those decisions evolved experientially over a period of three years of interaction with the commercial space infrastructure as illustrated in Figure 3-1. The primary data gathering instrument was designed to make use of available computer technology and facilitate participation from a broad spectrum of respondents who were geographically dispersed. As discussed in Chapter 2, the analysis techniques were derived from research in the field of nonlinear dynamics. New ways of analyzing and presenting the data resulted in the formulation of two hypotheses (H_1 and H_2, to be presented in Chapter 4) which represent potential tools for reduction of uncertainty in complex, nonlinear, dynamic decision environments. Figure 3-6 is a pictorial representation of the process of methodological development.

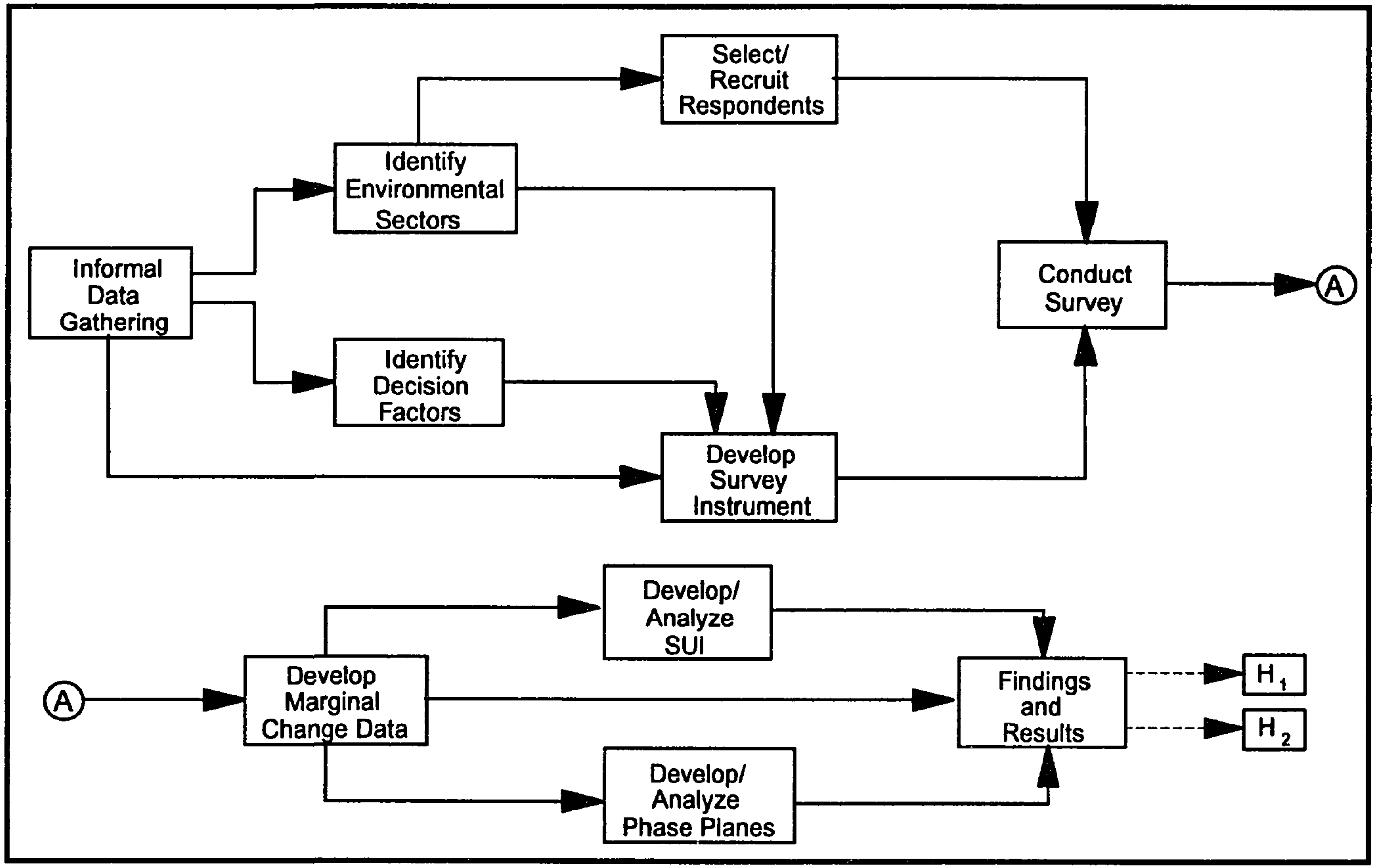


Figure 3-6. Methodological Process

CHAPTER 4

FINDINGS AND RESULTS

The following paragraphs present and discuss the findings and results of the data analysis.

Filtered Marginal Change Data

The data set derived from the polling/filtering method for marginal change data described in Chapter 3, and decision rationale for each data point are presented in Appendix E. The data set is reproduced here as Table 4-1. These are the data used in the remainder of the analysis.

TABLE 4-1

FILTERED MARGINAL CHANGE DATA

Year Pair	'85/'86	'86/87	'87/'88	'88/'89	'89/'90	'90/'91	'91/'92	'92/'93	'93/'94
Launch Activity	-59.69	-5.00	5.62	1.64	18.13	1.33	5.78	3.36	-0.94
Launch Costs	-1.67	-2.92	-0.78	-0.31	2.29	0	1.25	2.03	3.75
Legal/Reg. Environ.	1.7	5.98	5.5	3.96	4.48	12.25	0.27	-4.64	-3.3
Fed. Admin. Support	2.41	4.8	6.5	4.64	0.31	-0.98	1.96	-1.25	-5.09
Competition	-1.76	5.88	1.88	12.19	16.57	9.27	-1.34	7.14	2.41
New Technology	3.84	9.22	11.72	19	-1.43	4.38	10.94	4.64	4.63
Public Support	-1.25	-13.96	-6.57	-6.5	-4.07	-2.5	-5.63	-1.13	-0.98
Academic Research	-19.79	-1.09	2.03	-1.25	3.13	-0.16	-1.72	-4.22	-7.71
NASA Support	-1.48	-1.17	0.15	0.78	-1.09	-5.63	-1.56	-0.08	-6.33
DoD Support	-0.27	3.04	3.21	3.3	0.63	1.07	6.72	10.36	13.96

Phase Planes for Pair-Wise Comparison of Marginal Changes in Decision Factors

There are certain repeatable limit cycle patterns which are characteristic of low order chaos. Classical Period 1 behavior is described by either no change in either factor or a constant change in one or both. In any case, the limit cycle is confined to one quadrant on the phase plane (or to the origin, if neither factor changes) and is (theoretically) described by a single point. Figure 4-1a shows a more realistic pattern which might be observed, with a tight clustering in one area.

Classic Period 2 behavior involves oscillation between Quadrants 1 and 3, indicating a positive change in both factors in one time period, followed by a negative change in both in the following period. The limit cycle would trace a continuous path close to the major axis of the phase plane, as shown in Figure 4-1b. A limit cycle traversing the minor (Quadrant 2 - Quadrant 4) axis is also possible. Other common Period 2 behavior is characterized by alternating positive and negative changes in one factor, while the other factor remains relatively constant. The limit cycle would appear similar to that of Figure 4-1c.

Classic Period 4 behavior is exemplified by the "bow-tie" pattern of the limit cycle, as shown in Figure 4-1d. This pattern is caused by one factor changing sense every period (the vertical axis in figure 4-1d) while the other changes sense every second period (the horizontal axis in 4-1d).

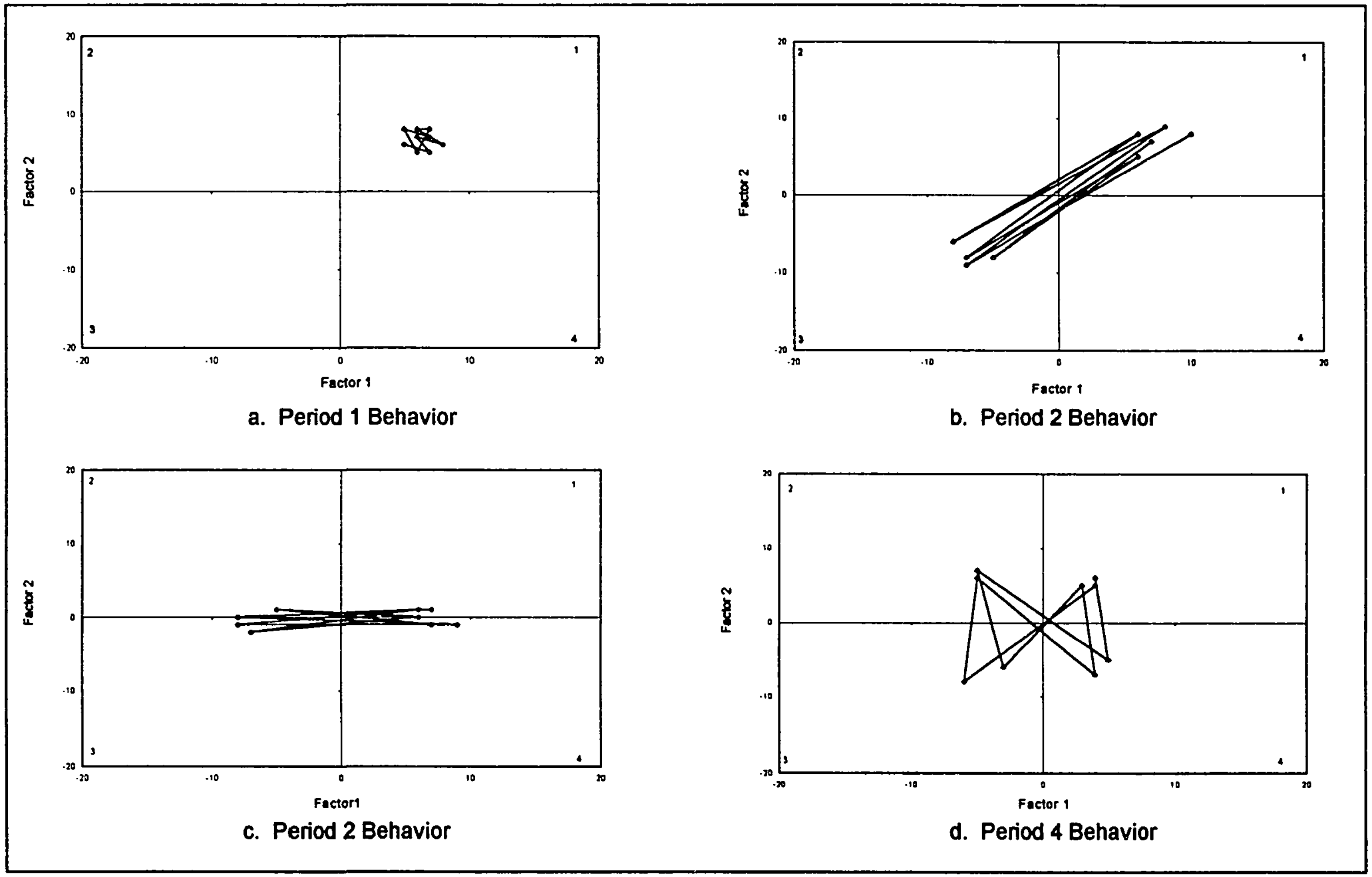


Figure 4-1. Classical Limit Cycle Behavior

With the ten factors, there are 45 pair-wise comparisons possible. A complete set of the phase plane diagrams is provided in Appendix F.

None of the phase plane trajectories shown in Appendix F are observed to demonstrate any of the foregoing low-order limit cycle behavior over the entire ten year period of investigation, thus indicating that all are described by a higher order of chaotic behavior. That is not to say, however, that no information can be derived. As Priesmeyer contends, complex patterns of behavior are driven by the combination of many lower-order chaotic interactions which are themselves deterministic, but too numerous to allow for direct observation.

The implication from the current data, then, is that extremely complex environmental forces are at work, which defy precise measurement and quantitative prediction of system behavior. It is also possible that factors other than the ones considered are affecting the system behavior.

Recent behavior (over the last four years) and projected behavior (for next year) do demonstrate some greater consistency, which allows certain relationships to be isolated and examined further to support generation of hypotheses via the analysis technique described for periodicity in Chapter 3. The data from that portion of the analysis are presented as Appendix G.

Figure 4-2 is the phase plane diagram for the NASA Support/Launch Cost factor-pair, which appears as Factor-Pair 16 in Appendix G. The trajectory traced by the dynamic interaction (in terms of phase plane quadrant visited) is

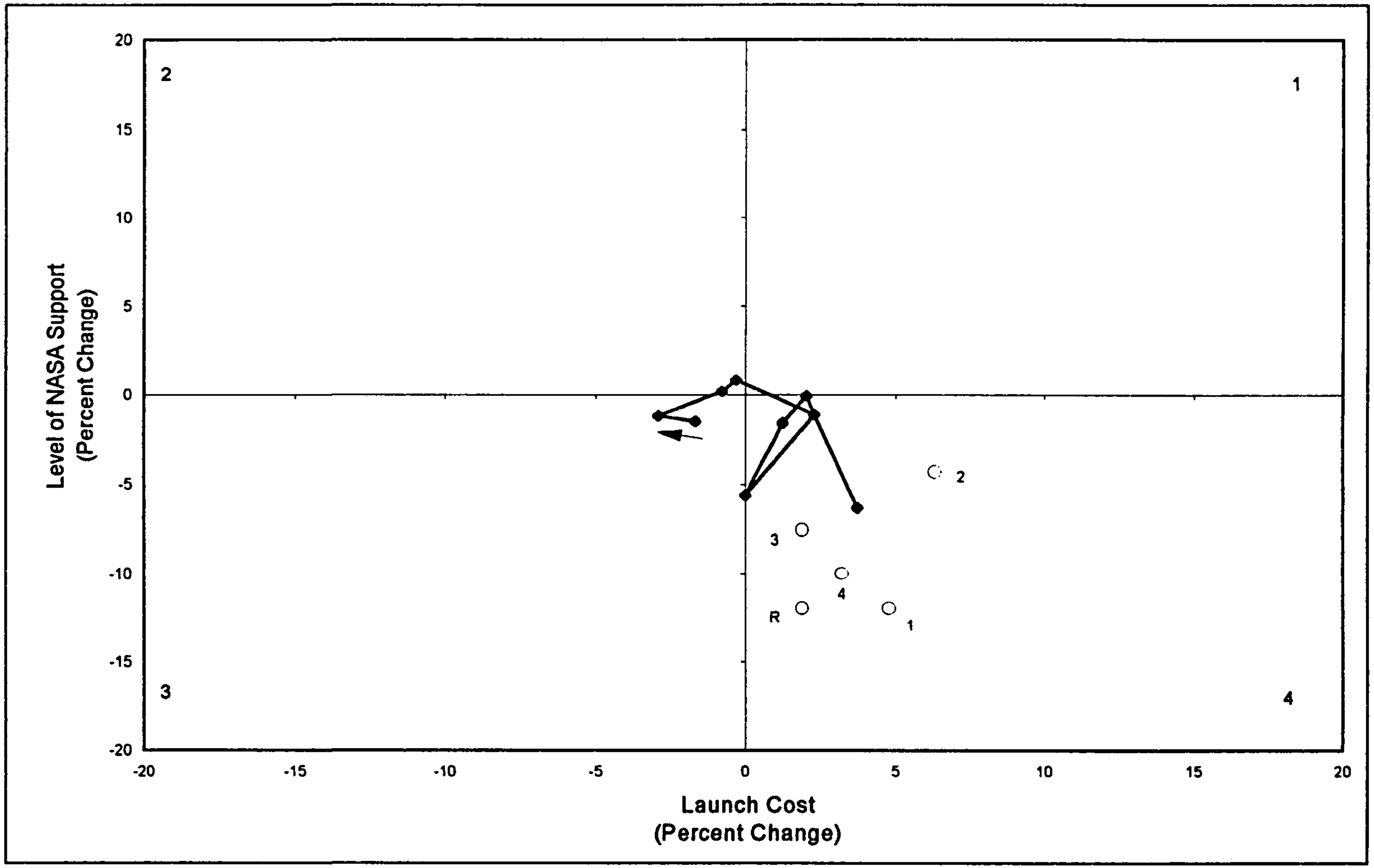


Figure 4-2. Phase Plane With "Next Point" Projections

listed chronologically. As is evident from Figure 4-2, the trajectory has remained in Quadrant 4 for the past four years. In the immediately preceding four year period, the trajectory visited Quadrants 3, 2 and 4. Under the classification scheme described in Chapter 3, the behavior of this interaction shifted from Period 8 (high-order chaos) to Period 1 (low-order chaos), as also shown in the "Periodicity" data field of Appendix G.

The "Projected Behavior" data field in Appendix G summarizes the results of the "next point" projections provided by the analysis respondents and the researcher. In the data field, the dual notation for each response indicates the projected quadrant number and whether the next point identified was closer to ("IN") or further from ("OUT") the phase plane origin than the last historical data point. These projections are also plotted as points labeled "R" and "1" through "4" in Figure 4-2, which illustrates, for this factor-pair, a consensus on the projected quadrant and a near-consensus on divergence from the origin. Additional illustrations of phase plane diagrams containing next point projections are provided in Appendix I.

The end result of that analysis is a listing of the most stable and predictable factor-pair relationship (lowest historical periodicity, supported by consensus regarding projected behavior) for each factor, as presented in Table 4-2. A graphical representation which more clearly shows these relationships is presented as Figure 4-3.

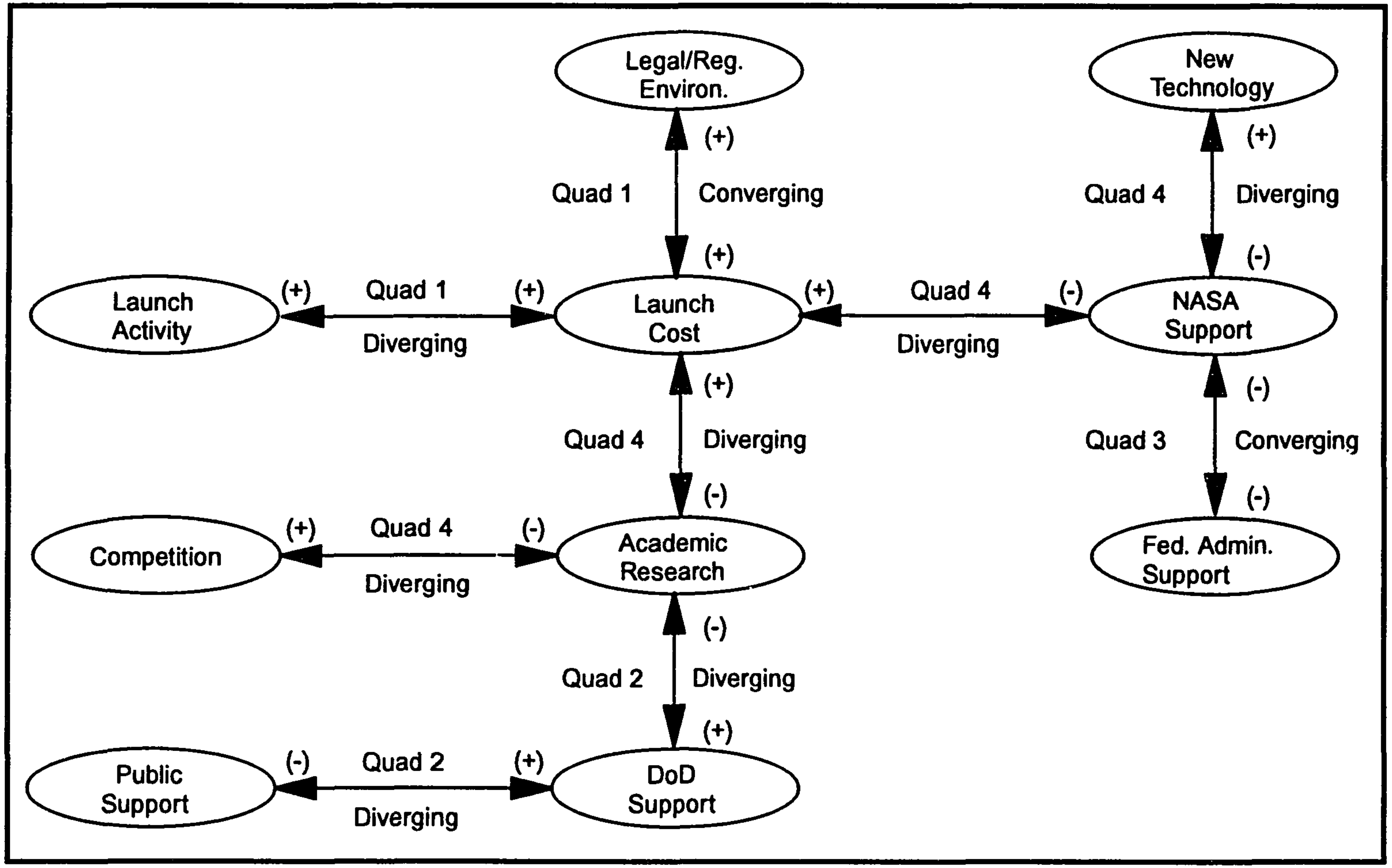


Figure 4-3. Most Stable Inter-Factor Relationships

TABLE 4-2

MOST STABLE INTER-FACTOR RELATIONSHIPS

Prime Factor	Related Factor	Periodicity	Quadrant
Launch Activity	Launch Cost	2	1
Launch Cost	Academic Research	1	4
Legal/Reg. Environ.	Launch Cost	2	1
Fed. Admin. Support	NASA Support	2	3
Competition	Academic Research	2	4
New Technology	NASA Support	1	4
Public Support	DoD Support	1	2
Academic Research	DoD Support	1	2
NASA Support	Launch Cost	1	4
DoD Support	Academic Research	1	2

In the figure, bi-directional arrows depict factor-pair relationships exhibiting the lowest order of chaos and most consistent next point predictions. The arrows are annotated with information concerning the projected future trajectories. Arithmetic signs at either end of the arrows indicate the direction of the marginal change of the connected factor. Adjacent to each arrow is the quadrant the trajectory is projected to visit, and an indication of whether the trajectory is projected to converge toward or diverge from the phase plane origin.

The most striking observation from Figure 4-3 is that one factor, Launch Cost, appears to be central in the diagram. It is directly linked to more factors than any of the others. The implication of this is that launch cost is a focal point in the decision system since it reacts more predictably in conjunction with the greatest number of other factors. From the point of view of a passive decision maker, it would be the best (but certainly not the only) variable in the system to use as a barometer. From the point of view of a proactive decision maker or policy maker, efforts to alter the cost of launch activities would be most likely to provide maximum leverage on the behavior of the decision environment.

Based on knowledge of the space launch industry, this conclusion is appropriate. The primary impediment to space exploration over the years has been the cost of space transportation (current estimates are between $5,000 and $10,000 per pound to low earth orbit).

Presentation of data in this manner can also lead to discovery of unimagined dynamic interactions which affect the system. As an example, consider the interaction between launch costs and launch activity shown in Figure 4-3. On the surface, it might seem that there would be a causal relationship in which decreasing launch costs would engender increasing launch activity. The data, however, indicate that the trajectory of the dynamic interaction between these two factors has spent most of its recent history in Quadrant 1, and is projected to return there by the majority of analysis respondents. Quadrant 1 is visited when the two factors are increasing simultaneously. An alternative explanation which could account for this behavior is that as the demand for launch capacity increases, in the absence of an increase in that capacity, the cost rises. In terms of the decision regarding whether or not to invest in space launch infrastructure, this kind of dynamic, if proven valid, would have a great deal of relevance.

Not all of the relationships in the figure are as readily decipherable. There are two possible explanations. The first is that the limitations of the data gathering process (to be discussed in detail subsequently) have led to an insufficient number of raw data points to develop a complete set of valid interactions. The other possibility is that there are dynamic relationships between factors that are unfamiliar to the researcher, and which warrant further investigation.

The foregoing discussion does not imply that interactions other than those isolated in Figure 4-3 cannot cause unexpected changes in the decision environment. It also is not offered as a *proof* of causality, since that data did not generate conclusive evidence of long term, repeatable periodic behavior. It does imply that causal relationships are more likely in the interactions of lower order chaos that have been isolated. Ashby (1956), in discussing Black Box Theory, makes the point that some systems are too complex for analysis of their internal mechanisms. System behavior, then, becomes predictable by observing how its outputs react in response to certain stimuli. Applying that theoretical perspective here implies that if certain dynamic relationships persist with a low order of chaos, even in the absence of an obvious one-to-one causal relationship, there is a useful element of predictability.

In the absence of other decision support data, or as a way of augmenting other data, this methodology serves to identify the dynamic relationships which possess a greater degree of predictability. In order to ensure robustness in the decision process, this kind of analysis should be repeated at specified intervals, and/or whenever the possibility of an extraordinary event arises. In the decision environment under study herein, one of the decisions supported would be to invest in additional space launch infrastructure of the nature which would reduce the cost of space access.

This methodology also serves another useful purpose. It provides a framework which focuses attention on system behavior, rather than on microanalysis using statistical data. Observing the trajectories and limit cycles of marginal change data on phase plane diagrams, as pointed out by Priesmeyer, has the potential to shed light on relationships which define system behavior in a way that conventional statistical data do not. Awareness of these relationships add conceptual depth to existing predictive tools such as scenario generation and "what if" analyses. The policy or decision maker armed with this information is better prepared to deal with highly complex and uncertain environments.

System Uncertainty Index (SUI)

As discussed in Chapter 3 (and illustrated in Figure 3-5), the numerical value of the SUI, for a given one-year time interval, is the absolute sum of the magnitudes of the vectors from the phase plane origin to the trajectories of all of the factor-pairs. While these values have no absolute meaning, trends and points of inflection in the index provide significant information. If the values are observed to be increasing in successive time intervals, it can be concluded that the trajectories (on average) are diverging from the origin, thereby encompassing a larger state space for potential behavior. The greater number of possible states that the system can assume equates to greater aggregate system variety and uncertainty (Ashby, 1956). It is, therefore, a measure of the amount of risk inherent in the investment decision.

Figure 4-4 shows the composite SUI for all decision factor-pair dynamic relationships. There are three important characteristics of the plotted data. The first is the high peak evident in the data from 1985 to 1986. The space shuttle Challenger explosion occurred in early 1986. This event had serious repercussions throughout the international space community. A high degree of uncertainty is, therefore, not unexpected in that timeframe. The second feature of interest is the peak in the two year period from 1988 to 1990. According to ancillary data provided by the survey respondents, a significant number of new launch service providers emerged during this time period, having a significant impact on the competitive environment.

The third, and perhaps most important feature of the plotted data of Figure 4-4 is the consistent upward swing over the most recent two year period. According to the ancillary data supplied, the timeframe coincides with the onset of cutbacks in federal funding for those NASA, DoD and research programs that

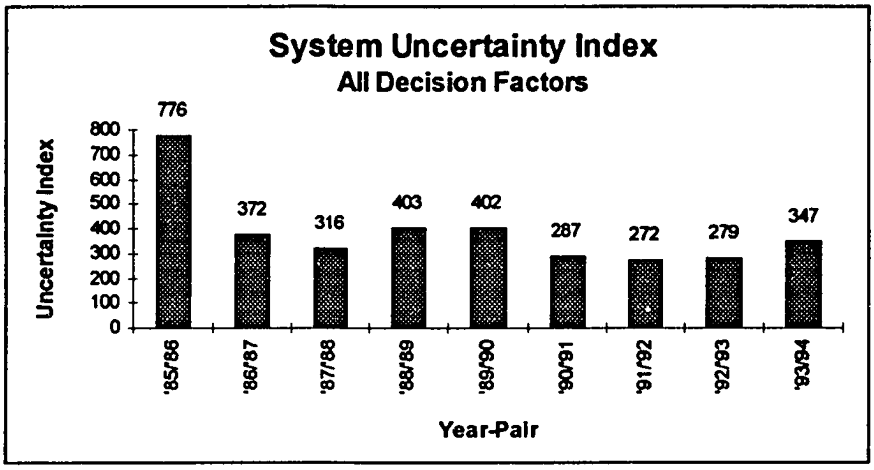


Figure 4-4. Composite System Uncertainty Index

are supporting space activities: a phenomenon which continues through the present. The unrest and uncertainty in these major U.S. infrastructure elements has pervaded the targeted decision environment. Data from the analysis respondents indicates that the trend will persist. Of their responses regarding the direction of the next point on the phase planes, 69.3% indicated that the next data point would diverge from the origin. It is also noteworthy that in Figure 4-3, seven of the nine interactions were predicted to be diverging.

This increasing trend in the level of uncertainty in the decision environment should act as a warning signal to potential investors that the risks are increasing. It must be noted, however, that Figure 4-4 only depicts rate of change in the dynamic environment. Given that some kinds of change can be beneficial (even though a steadily increasing rate of change is indicative of instability), it is advisable to further investigate the elements which contribute most significantly to this rise in the level of uncertainty.

Table 4-3 contains the SUI data for each of the factors as compared to the other nine. Graphic representations of these data are contained in Appendix H. Remembering that the ancillary data indicated that the increased level of uncertainty related to federal funding cutbacks and agency shake-ups, the SUI data for four factors, Support of the Federal Administration, Level of Academic Research, NASA Support and DoD Support, were examined, with the following observations concerning the two most recent time periods:

- Table 4-3 shows that the rate of change in the level of support by the federal administration declined slightly (from 42 to 41) and then rose sharply (from 41 to 67). As shown in Table 4-1, the contribution of this factor to the system uncertainty has been comprised of changes in the negative (undesirable) direction, that is, a reduction in the level of support by the federal administration.

- The rate of change in the level of academic research rose dramatically in each of the two periods (from 41 to 55 and from 55 to 85). The contribution of this factor has also been in the negative (undesirable) direction, that is, a reduction in the level of research activity.

- The rate of change in the level of NASA support declined slightly (from 40 to 39) and then increased sharply (from 39 to 75). The contribution of this factor has also been in the negative (undesirable) direction, that is, a reduction in the level of support by NASA.

- The rate of change in the level of DoD support rose substantially in each of the time periods (from 72 to 99 and from 99 to 132). The contribution from this factor has been in the positive (desirable) direction, that is, an increase in the level of support by DoD.

TABLE 4-3

SYSTEM UNCERTAINTY INDICES

FACTOR	'85/'86	'86/'87	'87/'88	'88/'89	'89/'90	'90/'91	'91/'92	'92/'93	'93/'94
Launch Activity	541	70	68	57	171	41	65	50	49
Launch Cost	98	59	44	53	59	38	39	43	60
Legal/Reg. Environ.	98	76	67	68	71	116	37	58	58
Fed. Admin. Support	101	69	74	71	52	40	42	41	67
Competition	98	75	48	124	159	93	39	75	54
New Technology	109	97	112	177	55	58	104	58	65
Public Support	96	133	74	83	68	47	64	40	49
Academic Research	222	53	48	55	63	38	41	55	85
NASA Support	97	53	44	54	54	66	40	39	75
DoD Support	94	60	54	64	52	40	72	99	132

All four of the factors exhibited increasing rates of change. Three of the four are observed to be changing in undesirable directions. An investor aware that the uncertainty in the environment is increasing and that the factors contributing to that uncertainty are changing in the undesirable direction would be better informed regarding potential risk, and adjust his or her required rate of return or payback period accordingly. In terms of the space launch infrastructure investment decision posed as the object of this study, the findings imply that the most robust strategy would be to piecemeal the infrastructure development, committing funds initially to those elements which can be implemented quickly and be capable of generating financial returns even in the absence of any further development.

What is also noteworthy about the data of Table 4-3 is that the SUI for the Launch Cost factor is consistently lower than that of the other factors. This correlates well with the finding discussed above and shown in Figure 4-3.

Summary and Hypotheses

The findings have demonstrated that the methodology developed herein can provide some utility in the arena of large-scale decision making and policy formulation. It can serve as another approach in an eclectic schema (Armstrong, 1968) of forecasting and policy decisions. This study is a preliminary investigation of the use of nonlinear dynamics techniques in this type of decision environment. Its size and scope were limited by the availability of time and resources, and its objective was to develop some hypotheses which provide direction for future research. Based on the findings discussed above, the following hypotheses are posed for further investigation:

H_1: The analysis of trajectories and limit cycles of marginal change data as described herein identifies dynamic relationships among decision factors which are most likely to influence the decision environment, when that environment is large, quantitative data is not readily available, and there exists a high degree of uncertainty and nonlinearity.

H_2: The System Uncertainty Index, as developed herein, is a measure of the aggregate uncertainty, and can support decision making by isolating trends in the magnitude of uncertainty in a given decision environment or making comparisons of uncertainty/risk levels between various decision environments.

Limitations

The objective of this research has not been to validate hypotheses, but to investigate new ways of reducing uncertainty and generate hypotheses regarding tools and techniques which may be of use in strategic decision making and policy formulation. There are certain limitations implicit in the methodology, most of which arise as a result of the practical constraints on resources and time to complete. The limitations fall into two general categories, biases and data validity, and are discussed in the paragraphs to follow.

Biases

For expediency in this study, the researcher selected the decision factors based on experience and content analysis of pertinent documentation. While the list of documentation (Appendix A) is considered comprehensive, it is by no means all inclusive. Therefore, some researcher bias may be associated with the selection of factors. However, for purposes of this exploratory research, potential omissions are not considered a serious threat to the validity of the data or results. In future research, this type of bias can be avoided by allowing the survey respondents (domain experts) to select the factors as part of the data collection process.

The survey instrument and its execution, due to the very limited personal contact involved, were relatively free from any researcher bias. Biases of the individual respondents were offset, to the greatest extent possible, by the directed sampling techniques which solicited respondents from diverse sectors of the environment. The limited sample size, however, cannot guarantee the absence of respondent bias.

The object of the analysis phase was to use the theoretical perspective of nonlinear dynamics to examine the data for meaningful patterns and indications of useful information. This kind of process is subject to researcher bias of the nature of seeing patterns which do not exist or "force fitting" data into anticipated results. Analysis of a judgmental nature (prediction of the next point on a phase plane) is especially susceptible to this type of bias. To provide integrity to the process, four people unfamiliar with the subject matter of the research were enlisted to repeat the analysis process employed by the researcher. They were provided only the information needed to accomplish the task. Only data points agreed upon independently by at least four of the five analysts were considered further.

A potential for researcher bias is also introduced in the filtering process used to develop the marginal change data for analysis. The risk was mitigated by a conservative approach which retained all data not proven to be inaccurate by ancillary data provided by other respondents. Of course there is still some potential for bias, since the researcher was the sole interpreter of the ancillary data.

Validity of Data and Results

Since the nature of the study was exploratory and limited resources were available, the sample size was small. Of twenty-one respondents invited and agreeing to participate, only eight submitted meaningful data. Consequently, the desired breadth of coverage of the sectors of the infrastructure was not achieved. The target size for responses for a given survey question (from which the decision factor marginal change data were developed) was a minimum of five. Of the ten questions, two (those pertaining to launch costs and level of academic research) received only four responses. All other questions received at least seven responses. With this limited amount of data, there is an issue of content validity, which is raised mainly by the potential for sampling errors. The question that must be addressed is whether the sample data used for analysis is truly representative of the universe (the decision environment) considered. As discussed in Chapter 3, the ancillary data collected was intended to, and in fact did, ameliorate the situation, but there still exists some degree of uncertainty in this regard.

The objective of the study was to examine decision environments which are large and difficult to quantify. Accordingly, the questions posed to the respondents were, by design, highly qualitative, subjective and broad in scope. The consequence of this is that an issue of construct validity is introduced by the degree of interpretation left to the respondents. The issue is whether the respondents were all answering the same questions; that is, whether all questions were perceived in the same way. Requests for additional supporting information (the ancillary data) built into the survey instrument met with limited success. In future research efforts, it would be advisable to include some mechanism (Delphi method or automated decision support system, for example) to arrive at a consensus among respondents based on supporting data extracted during the process.

The analysis of the dynamic relationships does not fully account for time lags in the effects of factors on one another. If the lag is relatively short (in the range of one to three years) the relationship is likely to be evident on the phase plane diagrams. However, for longer lags (five years or more) such as may be encountered in a research-technology-launch cost relationship, the proportion of the lag time to the total time period examined would make it very difficult to detect any relationship. On the other hand, meaningful effects of *perceptions* and *expectations* regarding causal relationships could certainly influence the decisions with much shorter delays, and therefore be significant to this analysis. For example, if a decision maker was aware of a large influx in research activity, the expectation of resulting reductions in launch costs might make the investment more appealing. In any case, subsequent research may consider dealing with this phenomenon by examining phase plane diagrams with variable time shifts incorporated.

Implications of Results

This research contributes the two hypotheses stated above, and the accompanying methodological framework, for eliminating some of the uncertainty in large-scale decision environments characterized by complex dynamic relationships and uncertainty regarding future behavior and factors which influence that behavior. It integrates the theoretical language and analytic processes of nonlinear dynamics and chaos theory into the language of decision theory and forecasting (a continuation of that begun by Priesmeyer). The methodology also encourages a holistic view of decision systems, as opposed to prediction based on extrapolation of a small number of statistical performance indicators. Validation of the hypotheses will add to the body of knowledge in decision theory and forecasting, providing additional tools for use in eclectic approaches.

A corollary contribution of the research is that the methodology can be used to support some of the widely used forecasting methodologies. Approaching the decision environment holistically and focusing on the dynamic interactions between factors that affect that environment can support the development of scenarios by illustrating what is and is not likely to occur within certain timeframes. It can also support "what if" and sensitivity analyses through its attention to the dynamics of the system.

The methodology described herein has applicability in decision environments other than that investigated in this study. It would be particularly applicable in advanced technological domains, rapidly growing industries and international endeavors, all of which are characterized by dynamic interactions that have not matured enough to be predictable.

The implications for future research are primarily concerned with the issue of validation. The traditional method of validation for a methodology which treats uncertainty in the future is to "live out" that future, chronicle the outcomes, and see if they lie within some tolerance bandwidth of the outcomes predicted. In a dynamic environment characterized by primary uncertainty, however, those tolerance bands lose their significance because the "ground rules" keep changing. The utility of the methodology developed herein is not its ability to predict the future, but its ability to shed light on the dynamic relationships which shape the future. The process of validation, then, must be a continuously unfolding and evolving process similar to that employed in robust sequential decision making. In the robust decision process, adjustments are made at specific decision points using knowledge acquired since the previous decision to develop a strategy which retains the greatest number of potentially good outcomes. In validating the hypotheses posed herein, additional data points can be added to the phase planes and uncertainty indices as future events unfold, and compared to the predictions generated. Some of the limitations of this study, which have been previously discussed, can be overcome in the design of subsequent data gathering efforts.

There are three additional recommendations for future research. This study, by design, relied entirely on qualitative data. For some of the factors (launch activity and launch cost, for example) some quantitative data exists. For other factors, related statistics which act as "indicators" of historical performance (NASA funding levels for space related research as an indicator of the level of academic research, for example). In future research efforts, these indicators should be incorporated into the raw data used to generate the marginal change data, or used as a basis of discussion if a method of consensus is used in the data gathering process.

The second recommendation addresses the validity issue through duplicity of findings. To accomplish this, it is recommended that the methodology be employed in a different research venue and the results compared. If the second study produces analytical results which appear reasonable (remembering that validity is not directly demonstrable), then credence is lent to the methodology.

The third recommendation is to attempt to develop a method of probing more deeply into the richness of interactions among the decision factors. The research described herein limited its investigation to pair-wise interactions. Future research could investigate higher order combinations of factors (three, four or five at a time).

CHAPTER 5

CONCLUSIONS AND REFLECTIONS

This research has been characterized as Exploratory Applied Research. The value of this type of research rests in its external validity - its ability to be generalized to other venues of investigation and practice. It is believed that the methodological process developed herein has broad generalizability.

The methodology is considered the primary contribution of the research. One of its benefits is that it provides a framework under which complex relationships can be observed and analyzed via patterns generated in phase space. This enables analysis of multifaceted decision scenarios by people who need not be expert in all of the relevant domains and disciplines. There are, however, some elements of the methodology which are critical to the outcome of the process. They warrant some further comment.

The most critical process element is the ability to enlist the respondents in such a manner that all relevant sectors of the environment are represented. The amount of effort that was expended to design the survey instrument and solicit respondents for the research was justified. In retrospect, the sample was still not considered sufficient to accomplish more than the proposition of two hypotheses based on the analysis of data.

The quality of respondents is also critical. In a less complex and more mature environment than the one selected for this research, this might not be as important an issue. In the case of commercial space launch infrastructure, however, most of the activity has been concentrated in the past decade. Consequently, finding individuals from all the required sectors who have been participants for that length of time was somewhat problematic.

In order to obtain a diversity of responses, the research was performed without any planned collaboration among respondents. But diversity became a double edged sword. On the one hand, the number of different viewpoints was maximized, which was beneficial. On the other hand, there was a likelihood that some sampling error was introduced by differing interpretations of the questions by the respondents. As stated in Chapter 4, it is the opinion of the researcher that some up-front cooperative activity among respondents would produce a more reliable set of data.

In actuality, there were instances of unintended respondent collaboration in the research. It was learned during follow-up contact that many of the respondents were acquainted with one another. Some of those relationships were known beforehand, but many were not. Of the eight responses used for analysis there was some degree of collaboration. In one instance, a survey diskette which was sent to one respondent was returned by another (the diskettes were coded for identification). It was later learned that both parties had supplied information in certain areas, and that some discussion had taken place. This in no way invalidated the data. On the contrary, this particular response was observed to have far more substantiating ancillary data than any of the other responses. The emergence of these relationships among respondents reinforces the observation that in this venue, there is a very small universe of potential respondents from which to draw a sample. The need for a methodology which maximizes sample size and the amount of information derived from each respondent becomes evident.

The hypotheses presented in Chapter 4 emerged as a result of looking at the numerical and pictorial/graphical data in a number of different ways. It is not the contention of the researcher that these hypotheses constitute an exhaustive list of the possibilities. The two that are presented meet the criteria of supporting actual observations of the environment (that is, they seem reasonable in light of current events), and of being of practical use to the decision maker.

To provide closure to the research and its outcomes, a look back at the initial research question posed in Chapter 1 is necessary. That question, restated, is: "Should an investment be made to develop infrastructure to support commercial space launch activities?" This research did not arrive at a simple "yes or no" answer to that question, and was not intended to, since the final decision in a real situation would also encompass factors relevant to the decision maker and his or her goals, objectives and risk tolerance. What does emerge from the analysis are two statements regarding such an investment which, with consideration given to the stated limitations of the research, could be used to assist in the strategic decision process.

> "If one were to invest in space launch infrastructure, the best return on investment is likely to come from activities which directly contribute to the reduction of launch costs."

> "In consideration of such an investment, one would be well advised to adjust the desired rate of return upward to compensate for the increasing level of uncertainty and risk in the environment."

REFERENCES

Aiginger, Karl (1987). Production and Decision Theory Under Uncertainty. New York: B. Blackwell.

Allaire, Yvan and Firsirotu, Mihaela (1989). "Coping with Strategic Uncertainty." Sloan Management Review, (v30, Spring), 7-16.

Allais, M. and Hagen, O. (1979). Expected Utility Hypotheses and the Allais Paradox. Dordrecht, Holland: D. Reidel Publishing Company.

Armstrong, J. Scott (1985). Long-Range Forecasting: From Crystal Ball to Computer. New York: John Wiley and Sons.

Arrow, Kenneth J. and Hurwicz, Leonid (1972). "An Optimality Criterion for Decision Making Under Ignorance," in C.F. Carter and J.E. Ford, eds. Uncertainty and Expectations in Economics. Oxford, Great Britain: Basil Blackwell.

Ascher, William and Overholt, William (1983). Strategic Planning and Forecasting: Political Risk and Economic Opportunity. New York: John Wiley and Sons.

Ashby, W. Ross (1956). An Introduction to Cybernetics. London: Methuen & Co., Ltd.

Beenhakker, H.L. (1975). Capital Investment Planning for Management and Engineering. Rotterdam, Netherlands: Rotterdam University Press.

Bolger, F. and Wright, G. (1993). "Coherence and Calibration in Expert Probability Judgment." Omega, (v21, no. 6, November), 629-644.

Bossert, James L. (1991). Quality Function Deployment: A Practitioner's Approach. New York: ASQC Quality Press.

Bullard, James and Butler, Alison (1993). "Nonlinearity and Chaos in Economic Models: Implications for Policy Decisions." The Economic Journal, (v103, July), 849-867.

Cartwright, T. J. (1991). "Planning and Chaos Theory." Journal of the American Planning Association, (v57, No. 1, Winter), 44-56.

Clemen, Robert T. (1991). Making Hard Decisions: An Introduction to Decision Analysis. Boston: PWS-Kent Publishing Co.

Cohen, Michele and Jaffrey, Jean-Yves (1980). "Rational Behavior Under Complete Ignorance." Econometrica, (v48, no. 5, July) 1281-1294.

Cohen, P. (1985). Heuristic Reasoning About Uncertainty - An AI Approach. Boston, MA: Pitman.

Crichton, Michael (1990). Jurassic Park. New York: Alfred A. Knopf, Inc.

Dagsvik, John K. (1994). "Discrete and Continuous Choice, Max-stable Processes, and Independence from Irrelevant Attributes." Econometrica, (v62, no. 5, September) 1179-1205.

Dixit, Avinash and Pindyck, Robert (1995). "The Options Approach to Capital Investment." Harvard Business Review, (v73, no. 3, May) 105-115.

Dyckman, T.R., Smidt, S., and McAdams, A.K. (1969). Management Decision Making Under Uncertainty. London: The MacMillan Company.

Easton, Allan (1980). Complex Managerial Decisions Involving Multiple Objectives. Huntington, NY: Robert E. Krieger Publishing Co.

Eoyang, Carson K. (1978). "Requisite Variety in Organizations." Proceedings of the 22nd Annual North American Meeting of the Society for General Systems Research, Washington, D.C., February 13-15.

Fishburn, Peter C. (1970). Utility Theory for Decision Making. New York: John Wiley and Sons.

Fishburn, Peter C. (1982). The Foundation of Expected Utility. Dordrecht, Holland: D. Reidel Publishing Co.

Friend, J.K. and Jessop, W.N. (1977). Local Government and Strategic Choice, 2nd Edition. New York: Pergamon Press, Ltd.

Gleick, James (1988). Chaos: Making a New Science. New York: Viking Press.

Gul, Faruk and Lantto, Outi (1990). "Betweenness Satisfying Preferences and Dynamic Choice." Journal of Economic Theory, (v52, October), 162-177.

Gupta, Shiv K. and Rosenhead, Jonathan (1968). "Robustness in Sequential Investment Decisions." Management Science, (v15, October), B-18 - B-29.

Henrion, Max, M. Granger Morgan, Indira Nair, and Charles Wiecha (1986). "Evaluating an Information System for Policy Modeling and Uncertainty Analysis." Journal of the American Society for Information Science, (v37, Sept.), 319-330.

Hey, John D. (1993). "Dynamic Decision Making Under Uncertainty: An Experimental Study of the Dynamic Competitive Firm," Oxford Economic Papers, (v45, no. 1, January) 58-82.

Hill, Percy, Bedau, Hugo, Chechile, Richard, Crochetiere, William, Kellerman, Barbara, Ounjian, Daniel, Pauker, Stephen, Pauker, Susan, and Rubin, Jeffrey. (1979). Making Decisions: A Multidiciplinary Introduction. Reading, MA: Addison-Wesley Publishing Co.

Holloway, Charles A. (1979). Decision Making Under Uncertainty: Models and Choices. Englewood Cliffs, NJ: Prentice-Hall.

Jedamus, Paul and Frame, Robert (1969). Business Decision Theory. New York: McGraw-Hill.

Kahneman, D. and Tversky, A. (1979). "Prospect Theory - Analysis of Decision Under Risk." Econometrica, (v47, n2), 263-291.

Karni, Edi (1985). Decision Making Under Uncertainty: The Case of State-Dependent Preferences. Cambridge, MA: Harvard University Press.

Kelsey, David (1993). "Choice Under Partial Uncertainty." International Economic Review, (v34, no. 2, May) 297-308.

Lawler, Andrew (1993). "Space Station Chaos Jeopardizes Coalition." Space News, (v4, no. 10, March 8-14), 1,20.

Loomes, G. and Sudgen, R. (1982). "Regret Theory - An Alternative Theory of Rational Choice Under Uncertainty." Economic Journal, (v92, n368), 805-824.

Machina, M.J. (1982). "Expected Utility Analysis Without the Independence Axiom." Econometrica, (v50, March) 277-323.

March, J.G. and Simon, H.A. (1958). Organizations. New York: Wiley.

Mason, David H. and Wilson, Robert G. (1987). "Future Mapping: A New Approach to Managing Strategic Uncertainty." Planning Review, (v15, May-June) 20-25.

Mehrez, A., Muzumdar, M., Acar, W., and Weinroth, G. (1995). "A Petri Net Model View of Decision Making: An Operational Management Analysis." Omega, (v23, no. 1, February) 63-78.

Mendell, Jay S., ed. (1985). Nonextrapolative Methods in Business Forecasting. Westport, Conn.: Quorum Books.

Middleton, Bruce S. (1995). "Launch Market Forecasts Often Mislead." Aviation Week and Space Technology, (v143, no. 2, July 10) 68.

Newbold, Paul (1986). Principles of Management Science. Englewood Cliffs, NJ: Prentice-Hall.

Patton, Michael Quinn (1990). Qualitative Evaluation and Research Methods. London: Sage Publications.

Prelec, Drazen and Loewenstein, George (1991). "Decision Making Over Time and Under Uncertainty: A Common Approach." Management Science, (v37, July), 770-786.

Priesmeyer, H. Richard (1992). Organizations and Chaos. Westport, Conn.: Quorum Books.

Priesmeyer, H. Richard and Baik, Kibok (1989). "Discovering the Patterns of Chaos." Planning Review, (Nov. - Dec.), 14-21, 47.

Prigogine, Ilya and Stengers, Isabelle (1984). Order Out of Chaos: Man's New Dialog With Nature. Toronto: Bantam New Age Books.

Radford, K.J. (1981). Modern Managerial Decision Making. Reston, VA: Prentice-Hall.

Raiffa, Howard (1968). Decision Analysis. Reading, Mass.: Addison-Wesley.

Richards, Diana (1990). "Is Strategic Decision Making Chaotic?" Behavioral Science, (v35), 219-232.

Rosenhead, Jonathan, Elton, Martin, and Gupta, Shiv K. (1972). "Robustness and Optimality as Criteria for Strategic Decisions." Operational Research Quarterly, (v23, no. 4), 413-431.

Savage, L.J. (1954). Foundations of Statistics. New York: Wiley.

Sayers, Chera L. (1991). "Statistical Inference Based Upon Non-linear Science." European Economic Review, (v35), 306-312.

Schniedler, D. (1989). "Subjective Probability and Expected Utility Without Additivity." Econometrica, (v57, May), 571-587.

Smilor, Raymond W. and Feeser, Henry R. (1991). "Chaos and the Entrepreneurial Process: Patterns and Policy Implications for Technology Entrepreneurship." Journal of Business Venturing, (v6), 165-172.

Stacey, Ralph (1993). "Strategy as Order Emerging From Chaos." Long Rang Planning, (v26, February), 10-17.

Stigler, G.J. (1950). "The Development of Utility Theory: I; II." Journal of Political Economy, (v58, August, 1950) 307-327, (October, 1950) 373-396.

Thompson, Arthur A. and Strickland, A. J. (1981). Strategy and Policy: Concepts and Cases. Plano, Texas: Business Publications, Inc.

Tonn, B. (1986). "Using Possibility Functions for Long-Term Environmental Planning." Futures, (v18), 795-807.

Tonn, B. (1991). "The Development of Ideas of Uncertainty Representation. (Research Policy and Review, part 34)." Environmental and Planning A, (v23, June), 783-812.

Wittrock, Bjorn (1979). "Long Range Forecasting and Policy Making: Options and Limits in Choosing a Future," in Tom Whitson, ed. The Uses and Abuses of Forecasting, London, MacMillan Press, Ltd.

Yager, R.R. (1980). "Aspects of Possibilistic Uncertainty. "International Journal of Man-Machine Studies. (v12, no. 3), 283-298.

APPENDIX A

LITERATURE AND CONTACTS USED AS INFORMAL DATA SOURCES

Literature Reviewed

Periodicals

Space News, Army Times Publishing Company
Washington Technology, TechNews, Inc.
Aerospace America, American Institute of Aeronautics and Astronautics
Aviation Week and Space Technology, McGraw-Hill, Inc.
NASA Tech Briefs, National Aeronautics and Space Administration
Innovations, Virginia's Center for Innovative Technology
Space Technology Innovation, NASA Office of Space Access and Technology
Technology Transfer Business, TechNews, Inc.
Discover, Time, Inc.
High Technology, Infotechnology Publishing Corp.
AIAA Student Journal, American Institute of Aeronautics and Astronautics
NASA Spin-off, NASA Office of Commercial Programs
Space FAX Daily, Space Age Publishing Company
Commercial Space Opportunities, NASA HQ, Office of Commercial Programs
Space Calendar, Space Age Publishing Company
Space, The Shephard Press
Inside Wallops, NASA Wallops Flight Facility

Reports and Documents

Design Challenges for Tomorrow's Manned Launch Systems, NASA Langley Research Center
Human Transportation System Study Final Report, NASA Johnson Spaceflight Center
Human Transportation System Study Architecture Evaluation Tool, NASA Johnson Spaceflight Center and Lockheed Engineering and Services Co.
Launch System Study Final Report: A Demonstration of Robustness for Space Transportation Architectures, Old Dominion University, Dept. of Engineering Management
Infrastructure Study (NAS 8-37588), Marshall Spaceflight Center and General Dynamics Space Systems Div.
Access to Space Study (Status Briefing Charts), NASA Access to Space Steering Committee
U.S. Space Launch Systems, Navy Space Systems Activity
Research and Test Facilities for Development of Technologies and Experiments with Commercial Applications, NASA Goddard Spaceflight Center
Virginia's Initiative for Commercial Space Launch Support at Wallops, Virginia's Center for Innovative Technology
In-Space Operations: Going to Work in Space, NASA Langley Research Center
Space: America's New Competitive Frontier, The Business-Higher Education Forum
Commercial Titan Briefing (Commercial Space Risk and Insurance Symposium), Martin Marietta Commercial Titan, Inc.
Payload Processing Facilities and Support for Commercial ELV and Shuttle Launches, Astrotech Space Operations, L.P.
A Survey on the Opinions and Attitudes of Investors on Commercial Space Initiatives, KPMG Peat Marwick
Accessing Space: A Catalog o Process, Equipment and Resources for Commercial Users, NASA HQ, Office of Commercial Programs

Reports and Documents (Cont'd.)

Overview of Policy, Market and Technology Options for Commercial Reusable Re-entry Satellites, NASA Ames, Office of Commercial Programs and Stanford University

Commercial Delta Launch Vehicle (Briefing to Commercial Space Risk and Insurance Symposium, McDonnell Douglas

The Atlas Family: Commercial Launch Services, General Dynamics Commercial Launch Services

Big, Dumb Boosters: A Low-Cost Space Transportation Option?, U.S. Congress, Office of Technology Assessment

Commercial Space Ventures: A Financial Perspective, U.S. Department of Commerce

Virginia Space Resource Directory, Virginia's Center for Innovative Technology

A Post Cold War Assessment of U.S. Space Policy, Vice President's Space Policy Advisory Board

Final Report to the President on the U.S. Space Program (1993), National Space Council

The Future of the U.S. Space Industrial Base, Vice President's Space Policy Advisory Board

The Future of the U.S. Space Launch Capability, Vice President's Space Advisory Board

1992 Research and Technology Report, Goddard Space Flight Center

United States Space Directory (1993), Space Publications

NASA Spinoff (1991, 1992), NASA HQ, Office of Commercial Programs

Virginia Focuses on Space, Virginia's Center for Innovative Technology

Commercial Experiment Transporter (COMET) technical and management reports, Center for Space Transportation and Applied Research

Final Report (to CIT): The Center for Commercial Space Infrastructure, Old Dominion University, Department of Engineering Management

Commercial Space Infrastructure Needs Assessment Survey: Report of Findings, Old Dominion University, School of Business and Public Administration

Contacts Established (by Infrastructure Sector)

Commercial Space Industry

Name	Organization
Mr. Roy Slinchum	Hughes STX
Mr. Dru Qazi	Hughes STX
Mr. Frederick Perkins	Standard Space Platforms Corp.
Ms. Bonnie Morris	Stanford Telecommunications, Inc.
Ms. Christine Gatewood	General Dynamics
Mr. Hollister Cantus	Lockheed Missiles & Space Co.
Dr. Phillip Cheney	Raytheon Co.
Mr. Dick Ullman	ITT Defense, Inc.
Mr. Barry Abzug	ITT Aerospace
Mr. John Mehoves	Orbital Sciences Corp.
Mr. Otto Hoernig	International Microspace
Dr. Richard Fleeter	AeroAstro Corp.
Mr. Larry Yermack	Fairchild Space and Defense Corp.
Mr. Ron Hodge	SPOT Image Corp.
Mr. Jesse Moore	Ball Corp.
Mr. Ed Yablonski	American Mobile Satellite Corp.
Mr. Dave Johnson	CTA, Inc.
Mr. Robert Cowls	McDonnell Douglas Space Systems Co.
Mr. Theodore Nanz	SPOT Image Corp.
Mr. Sam Mihara	McDonnell Douglas Space Systems Co.
Ms. Bonnie Soodik	McDonnell Douglas Space Systems Co.
Mr. Steve Lawson	Thiokol Corp.
Mr. R. S. Sapp	Lockheed Corp.
Dr. Mourice Miller	Lockheed Engineering and Services Co.
Mr. Robert Young	Lockheed Corp.
Mr. Ken Johnson	GE Astrospace
Mr. Robert Hager	Boeing Missiles and Space Group
Mr. Robert Horowitz	GE Astrospace
Mr. Richard Grant	Boeing Missiles and Space Group
Ms. Elyse Nicholson	Rockwell International/Rocketdyne
Mr. Henry Dinenno	Rockwell International Corp.
Ms. Mary Lou Kromer	Rockwell International Corp.
Ms. Ginger Emry	Rockwell International Corp.
Mr. Don Carter	Rockwell International Corp.
Mr. Paul Hirsch	Rockwell International Corp.
Mr. Robert Glaysher	Rockwell International Corp.
Mr. Mark Schwene	Hughes Space and Communications Co.
Mr. Bill Moore	Hughes Space and Communications Co.
Mr. Steve Pilcher	Hughes Space and Communications Co.
Mr. Paul Bachar	Hughes Space and Communications Co.
Mr. Fred Stang	Space Systems/Loral
Ms. Elaine Hinsdale	Grumman Aerospace Corp.
Mr. Ed Yablonski	American Mobile Satellite Corp.
Mr. Dom Mack	Integral Systems, Inc.
Mr. Ivor Knight	Communications Satellite Corp.
Mr. Joseph Jerger	Space Vector Corp.
Mr. Howard Svigals	GTE Spacenet Corp.

Commercial Space Industry (Cont'd.)

Name	Organization
Mr. Alvin Reeser	Spacehab, Inc.
Mr. Thomas Zakrzewski	Nichols Research Corp.
Mr. Phillip Bruce	Space Applications Corp.
Mr. Mark Daniels	EER Systems Corp.
Mr. Tom Ramberg	Space Applications Corp.
Mr. Chris Bourassa	Storm Integration, Inc.
Mr. Bill Grieser	Storm Integration, Inc.
Mr. David Sterling	Motorola, Inc.
Mr. R. D. Anderson	Pratt & Whitney
Mr. Rick Andrews	KPMG Peat Marwick
Mr. John Jaques	Martin Marietta Corp.
Mr. Kurt Bassett	Martin Marietta Civil Space & Communications Co.
Mr. John Lent	Martin Marietta Corp.
Mr. John DeGeneres	Martin Marietta Manned Space Systems Group
Mr. Feltus Kennedy	Martin Marietta Manned Space Systems Group
Mr. Robert Beale	General Electric Co.
Mr. Bill Benner	Unisys Corp.
Mr. Henry Berry	Engineering, Inc.
Mr. Francis Bloomcamp	McDonnell Douglas Corp.
Mr. H. L. Brewer	Northrup Corp.
Mr. James Burns	Centel Cellular Co.
Mr. Joseph Casas	Spacetec Ventures, Inc.
Mr. James Cannon	Technology Applications, Inc.
Mr. Richard Coffman	BDM International, Inc.
Mr. Richard Cochran	Northrup Worldwide Aircraft Services, Inc.
Mr. Ted Cors	L T Aerospace and Defense Co.
Mr. William Crowe	Booz-Allen & Hamilton, Inc.
Mr. J. E. Cvik	Raytheon, Co.
Ms. Christine DeHaven	The Boeing Co.
Mr. Ben DeVane	Westinghouse Electric Corp.
Mr. Thomas Ehrenberger	E-Systems
Mr. Donald Elliott	Lockheed Corp.
Mr. James Emory	Litton Data Systems
Mr. Bill Fedor	The Boeing Co.
Mr. Bruce Ferguson	Orbital Sciences Corp.
Mr. Terry Feist	General Electric Co.
Mr. Doyle Franklin	UNISYS Corp.
Mr. George Golden	Rockwell International/North American Aircraft
Mr. Patrick Haney	Lockheed Corp.
Mr. E. J. Higgins	Teledyne Hastings-Raydist
Mr. Robert Kelly	Lockheed Engineering
Mr. Robin Kozelka	Loral Electronic Systems
Mr. John Langford	Aurora Flight Sciences Corp.
Dr. Byron Lichtenberg	Payload Systems, Inc.
Mr. R. A. Magnum	McDonnell Douglas Corp.
Mr. Kevin McCoy	General Dynamics Corp.
Mr. Roy Myers	Rockwell International
Mr. Landon Overby	Contel Federal Systems
Mr. Thomas Pearson	EER Systems Corp.
Mr. Howard Pedolsky	Orbital Systems Ltd.
Mr. Pete Perkins	TRW Space and Technology Group

Commercial Space Industry (Cont'd.)

Name	Organization
Mr. Duane Perry	Allied-Signal Aerospace Co.
Mr. Richard Price	Grumman Corp.
Mr. Donald Quinn	Hughes Aircraft Co.
Mr. Mandell Reynolds	Computer Sciences Corp.
Mr. Vincent Schultz	Booz Allen & Hamilton, Inc.
Mr. Scott Stith	General Electric Government Services Co.
Mr. Richard Stoessner	Sikorsky Aircraft Co.
Mr. Paul Tobin	Wyle Laboratories
Mr. Moffette Tharpe	EER Systems
Mr. Marco Zanetti	Martin Marietta Corp
Mr. Edward Haugland	General Research Corp.
Mr. Ernest Briel	BRPH Architects-Engineers
Dr. Thomas Wright	EER Systems
Mr. Jim Lojocono	SKW Corporation
Mr. Wesley Werling	EER Systems
Mr. Michael Kiya	SKW Corporation
Mr. Wayne Finger	Reynolds, Smith and Hills, Inc.
Dr. Marshall Kaplan	Veda Incorporated
Mr. Bill Derdock	Lockheed Space Operations Co.
Mr. Ron Sabatino	Lockheed Space Operations Co.
Mr. Ernest Bedegrew	Lockheed Missiles and Space Co.
Mr. Edward Matthews	Conatec, Inc.
Mr. David McGowan	Orbital Sciences Corp.
Mr. Brian Hughes	American Rocket Company
Mr. Robert Mellor	Lockheed Space Operations Co.
Mr. Dennis McGinley	AlliedSignal , Inc.
Mr. Gene Steiger	Lockheed Missiles and Space Co.
Mr. Art Waite	BRPH Architects-Engineers
Mr. Art Perry	American Space Technology, Inc.
Mr. Stephen Morgan	Starsys Global Positioning, Inc.
Mr. Jack Koletty	AlliedSignal, Inc.
Mr. Richard Scredon	Veda, Incorporated

NASA

Dr. George Garrison	Center for Space Transportation and Applied Research
Mr. Joe Pawlick	Center for Space Transportation and Applied Research
Mr. Sidney Pauls	NASA Langley Research Center
Mr. John Emond	NASA Office of Commercial Programs
Mr. Ray Whitten	NASA HQ, Office of Commercial Programs
Mr. Charles Cockrell	NASA Langley Research Center
Mr. Larry Rowell	NASA Langley Research Center
Mr. Ray Stanley	NASA Wallops Flight Facility
Mr. Terry Potterton	NASA Wallops Flight Facility
Mr. Ed Dean	NASA Langley Research Center
Mr. Bruce Underwood	NASA Wallops Flight Facility
Mr. Sidney Pauls	NASA Langley Research Center
Mr. John Emond	NASA HQ, Office of Commercial Programs
Mr. Keith Koehler	NASA Wallops Flight Facility

Federal, State and Local Government Agencies

Name	Organization
Mr. James Carnes	Department of Defense Energy Directorate
Mr. Charles Kline	U.S. DoT, Office of Commercial Space Transportation
Dr. Mario Fiori	U.S. Department of Energy
Mr. Richard Scott	U.S. DoT, Office of Commercial Space Transportation
Mrs. Stephanie Myers	U.S. DoT, Office of Commercial Space Transportation
Mr. E. W. Davis	VA Dept. of Economic Development
Mr. Randy Davis	Hampton Roads Chamber of Commerce
Mr. Julius Denton	VA Peninsula Economic Development Center
Mr. Arthur Fisher	Eastern Shore of VA Economic Development Comm.
Ms. Donna Girardot	Hampton Roads Chamber of Commerce
Mr. Henry Hofheimer	Future of Hampton Roads
Mr. Terry Holzheimer	VA Dept. of Economic Development
Mr. John Hornbeck	Hampton Roads Chamber of Commerce
Ms. Connie Long	Hampton Roads Chamber of Commerce
Mr. Alvin Tompkins	VA Peninsula Chamber of Commerce
Mr. Greg Wingfield	Forward Hampton Roads
Dr. Dana Hamel	VA Center for Public/Private Initiatives
Capt. Robert Masten	U. S. Naval Weapons Station
Col. Edward Nicastri	Defense Advanced Research Projects Agency
Ms. Cathleen Magennis	VA Dept. of Economic Development
Mr. Peter Fitzpatrick	VA Dept. of Economic Development
Mr. James Witherspoon	VA Department of Economic Development
Mr. Michael Miller	Virginia's Center for Innovative Technology
Mr. Jack Bonniwell	Eastern Shore of VA Economic Development Comm.
Mr. Keith Bull	Eastern Shore of VA Economic Development Comm.
Hon. Herbert H. Bateman	U.S. Congress
Ms. Susan Berry	Office of Sen. John Warner
Ms. Patricia Spurlock	Office of Sen. Charles Robb
Mr. Pat Ladner	Alaska Aerospace Development Corp.
Mr. Daniel Kuennen	MD Rural Development Center
Mr. Wayne Sterling	VA Department of Economic Development
Mr. Paul Berge	Accomack-Northampton Planning District Commission
Ms. Marsha Schachtel	MD Dept. of Economic and Employment Development
Ms. Shana Dale	U.S. Congress, Science, Space and Tech. Committee
Mr. Jeff Hofgard	White House Office of Science and Technology Policy
Mr. Bill Meyer	MD Dept. of Economic and Employment Development
Maj. James Knauf	USAF, Office of the Assistant Secretary for Acquisition

International Entities

Mr. Wang Yan	China National Aero-Technology Import/Export Corp.
Mr. Chris Faranetta	NPO Energia
Mr. Jeff Manber	NPO Energia

Academic and Research Centers

Name	Organization
Ms. Barbara Hale	Center for Cell Research
Dr. Marianna Long	Center for Macromolecular Crystallography
Dr. Charles Bostian	Center for Commercial Space Communications
Mr. Donald Bishop	Center for Space and Advanced Technology
Mr. C. L. Britt	Research Triangle Institute
Mr. Suman Ganguly	Center for Remote Sensing
Mr. J. G. Bowman	Institute of Long Range Studies
Dr. William Glenn	Space Communications Technology Center
Mr. David Cummings	Universities Space Research Association
Dr. John Logsdon	Space Policy Institute

Legal Providers

Ms. Janice Bellucci	Attorney at Law
Mr. F. Kenneth Schwetje	Aegis Research Corp.

Media

Ms. Karen Davis	Virginian Pilot and Ledger Star
Mr. Jim Gifford	Space News

Financial Providers

Mr. Frank DiBello	Space Vest Management Group

Associations and Organizations

Ms. Joanne Padrone	American Institute of Aeronautics and Astronautics
Ms. Mary Sandy	Virginia Aerospace Business Roundtable

Insurance Providers

Mr. Frederick Hauck	International Technical Underwriters, Inc.

APPENDIX B

SURVEY INSTRUMENT

SOFTWARE SCREENS AND RESPONDENT INSTRUCTIONS

COMMERCIAL SPACE INFRASTRUCTURE SURVEY

In support of a Ph.D. Dissertation in Engineering Management

Wayne Woodhams
Department of Engineering Management
Old Dominion University
Norfolk, Virginia 23529
(804) 683-5478

CLICK HERE TO BEGIN SURVEY

If operating from a floppy disk drive, you must identify the drive you are using (A or B) by clicking on the appropriate button below.

Disk Drive = A: ◉

Disk Drive = B: ○

If this is your first time through the survey, or if you are unsure of how to proceed, click on the INSTRUCTIONS button below for a brief tutorial.

If you wish to bypass the tutorial and start the survey now, click on the START button below.

INSTRUCTIONS START

TUTORIAL

This computerized data gathering instrument was custom designed for this application, using Microsoft Visual Basic 3.0.

Note that this program will not run unless the DOS SHARE program is executing. If it is not part of your ATTOEXEC.BAT file, you must exit Windows and type "SHARE/L:500" at the DOS prompt, hit ENTER, and restart Windows.

This survey requests that the respondent supply data in one or more of ten topic areas relating to commercial space activities. You were invited to participate because of your knowledge in at least one of these areas. Please feel free to respond in any additional areas in which you feel comfortable.

Also, please feel free to collaborate with colleagues in responding. If a colleague wishes to respond individaully, please provide his/her name and E-mail (or postal) address in the final comments section of the survey, or make a copy of this transmittal for his/her use.

Each screen has command buttons like the ones you see below. Clicking your mouse button on any of them allows you to control the program execution. Click on the CONTINUE button to proceed, or the QUIT button if you wish to stop here to activiate the SHARE program.

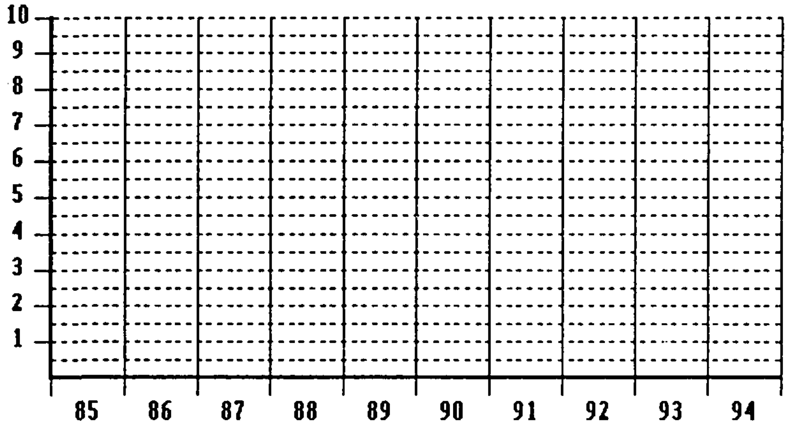
CONTINUE QUIT

TUTORIAL

Each data entry screen asks a question relating to the performance of some factor relating to commercial space, and how it has varied over the past ten years. The responses requested are qualitative rather than quantitative and are provided by you in a graphic format such as the one shown below. The levels are normalized to a scale of 1 to 10.

When responding, first select the year in which the greatest level of the particular factor has been observed, and rate that year as a "10". Then rate all other years in comparison.

Enter data by clicking your mouse when the pointer is where you wish on the grid. Try experimenting with the sample grid below.



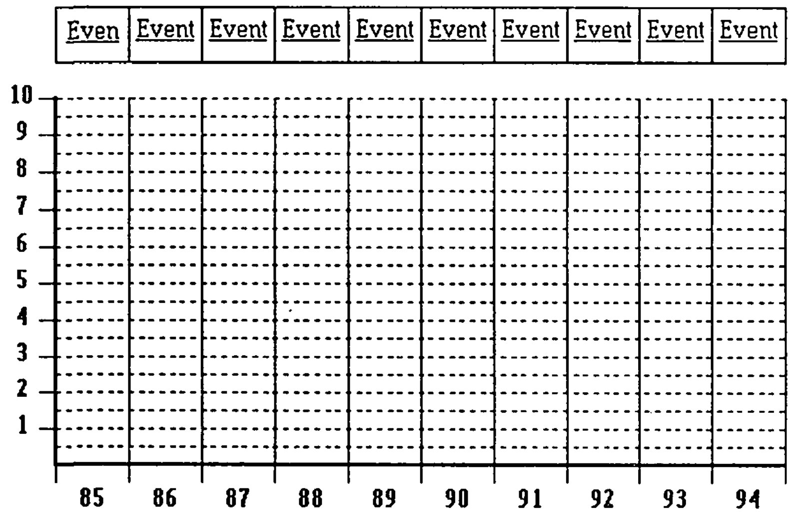
When you're satisfied,
click on CONTINUE.

CONTINUE

TUTORIAL

Above the data entry grid appears a bank of "Event" buttons like those below. Clicking on any one of them will open a screen that asks you to identify significant events associated with the year in question.

A very important use of the data will be to analyze maxima, minima and points of inflection, so please use the Event buttons to provide any available information regarding those phenomena.



Note that the Event buttons are not active in this tutorial.

CONTINUE

TUTORIAL

Note that none of the buttons below are active except for CONTINUE.

To the right of the data entry grid are two additional buttons as shown to the right. Clicking on the DATA SOURCE button opens a screen that asks you to identify the source of any statistical data used to support your response.

DATA SOURCE

Clicking on the COMMENT button opens a screen which allows you to make any additional comments which you might consider relevant.

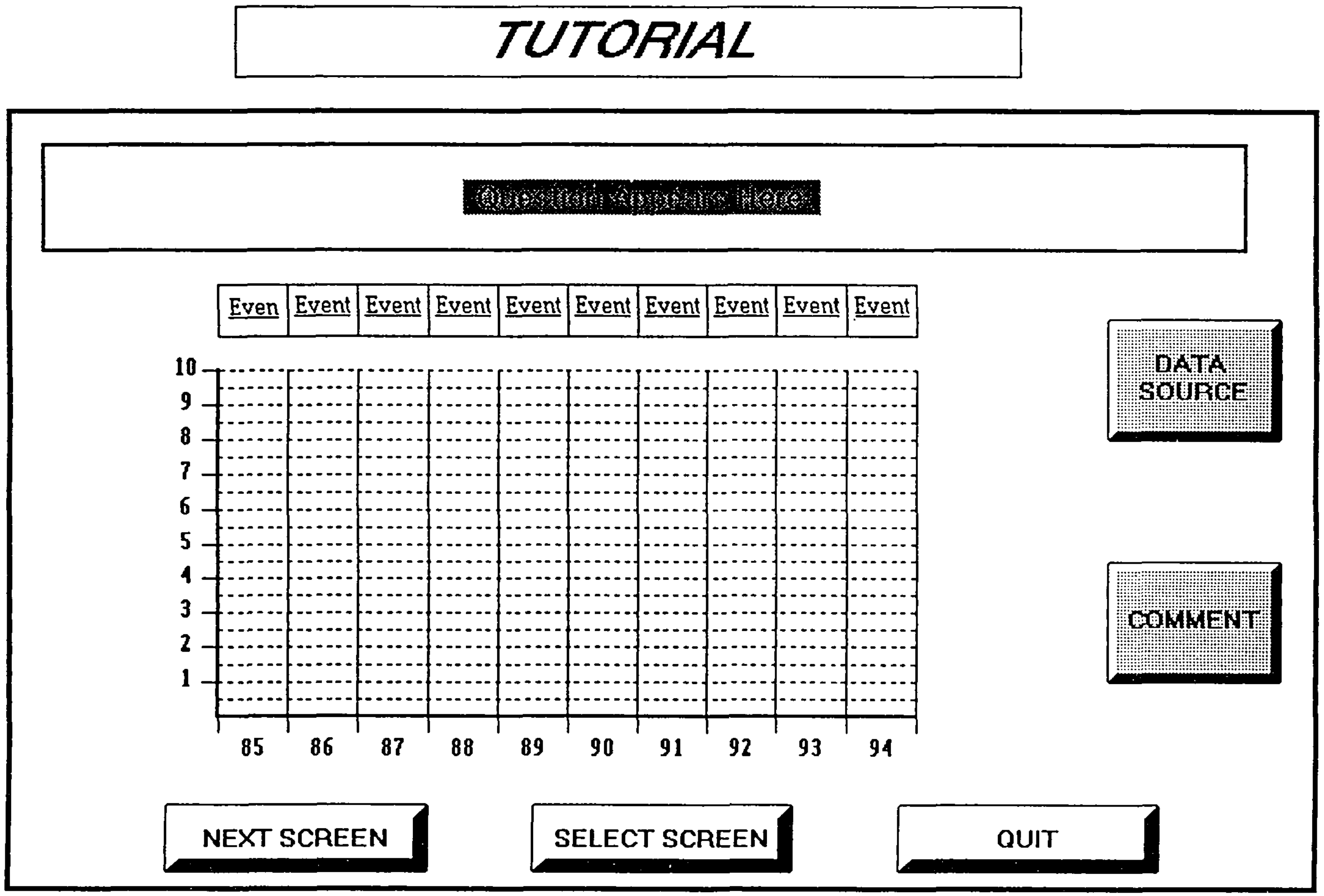
COMMENT

The three command buttons which appear at the bottom of each data entry screen are shown below. Clicking on the NEXT SCREEN button opens the next data screen for use. Clicking on the SELECT SCREEN button opens a menu from which you can select any data screen to open. Clicking on the QUIT button saves all data and ends the survey session. You may quit and restart as many times as you like without losing data.

NEXT SCREEN | SELECT SCREEN | QUIT

To see a sample of the data entry screen, click on CONTINUE.

CONTINUE



To view a listing of the questions, click on CONTINUE.

CONTINUE

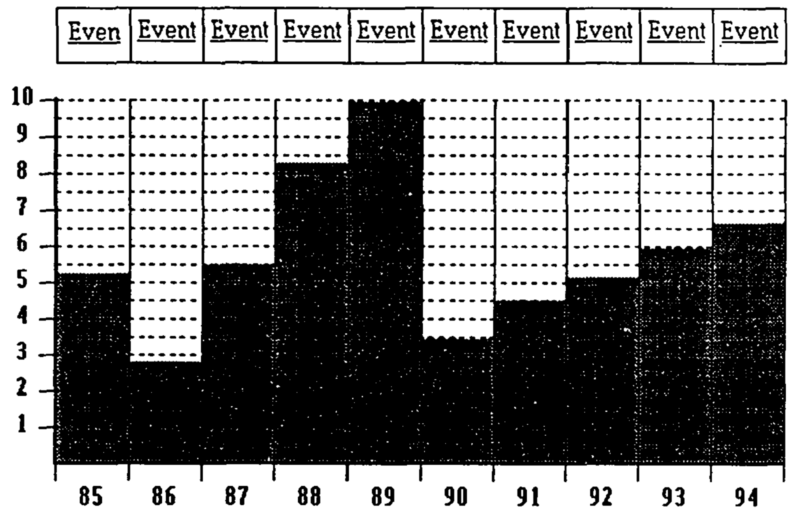
PREVIEW OF QUESTIONS

Data Entry Screen #1	What has been the relative level of small to mid-sized (500 to 8,000 lbs. to LEO) launch activity over the past 10 years?
Data Entry Screen #2	How has the cost per pound of payload mass to LEO, for Expendable Launch Vehicles, varied over the past 10 years?
Data Entry Screen #3	How strongly has the legal/regulatory environment supported commercial space activities over the past 10 years?
Data Entry Screen #4	How strongly has the federal administration supported commercial space activities over the past 10 years?
Data Entry Screen #5	What has been the relative level of competition (how many small to mid-sized launch providers, world-wide) over the past 10 years?
Data Entry Screen #6	What has been the relative level of new technology introduction for small to mid-sized ELV's and satellites over the past 10 years?
Data Entry Screen #7	How supportive of space activities has the public been, over the past 10 years?
Data Entry Screen #8	What has been the relative level of space-related academic research activity over the last 10 years?
Data Entry Screen #9	How has NASA's support of commercial space varied over the past 10 years?
Data Entry Screen #10	How has DoD's support of commercial space varied over the past 10 years?

BEGIN SURVEY QUIT

DATA ENTRY SCREEN #1 - LAUNCH ACTIVITY

What has been the relative level of small to mid-sized (500 to 8,000 lbs. to LEO) launch activity over the past 10 years?



DATA SOURCE

COMMENT

NEXT SCREEN

SELECT SCREEN

QUIT

SCREEN 1 EVENTS

Please describe significant event(s) of 1990 in the box below.

1985:

1986:

1987

1988

1989

1990

1991

1992

1993

1994

RETURN TO DATA ENTRY FORM

DATA SOURCES

Please identify the source of any statistical data

[illegible]

[illegible]

Screen 2:

Screen 3:

Screen 4:

Screen 5:

Screen 6:

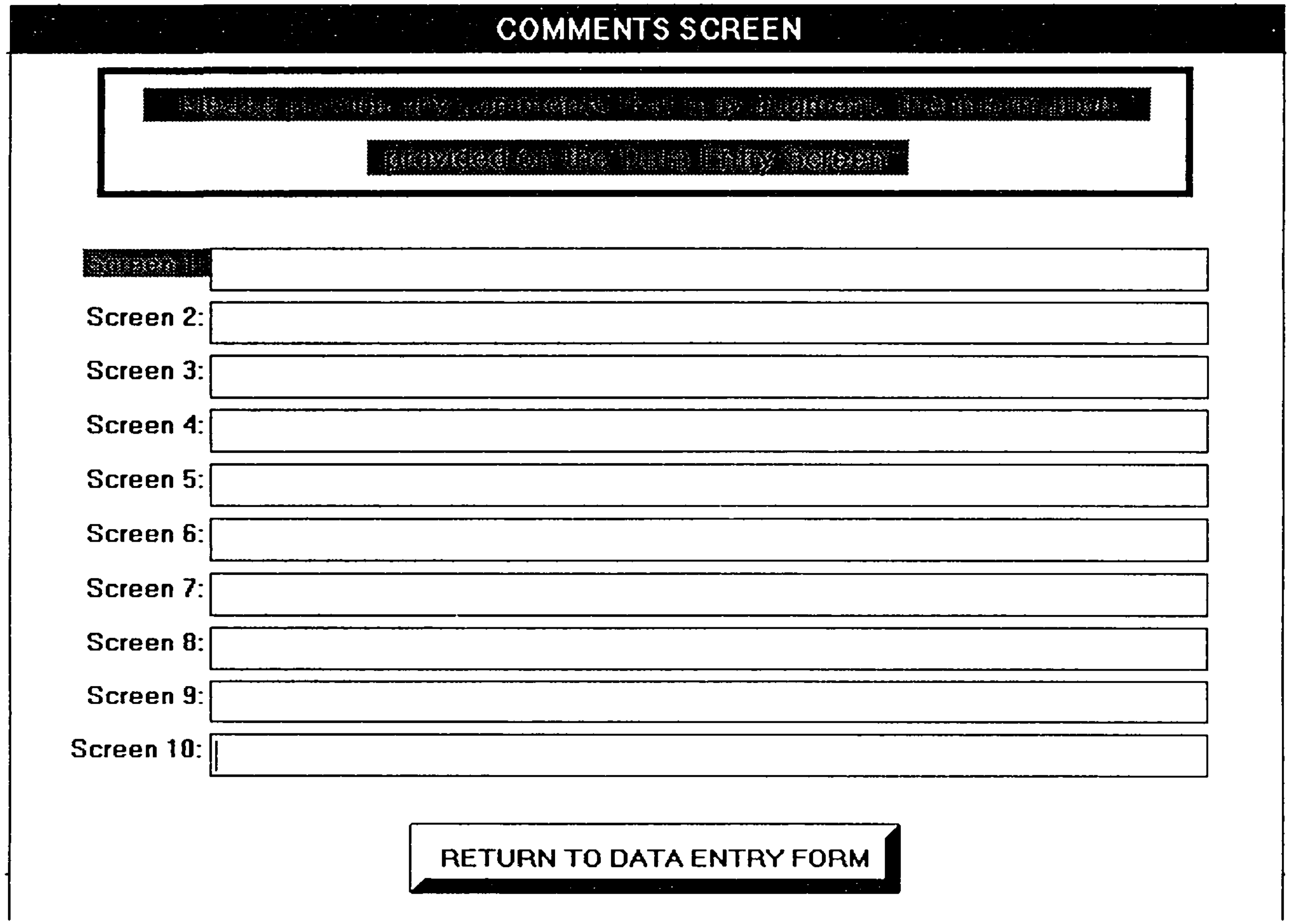
Screen 7:

Screen 8:

Screen 9:

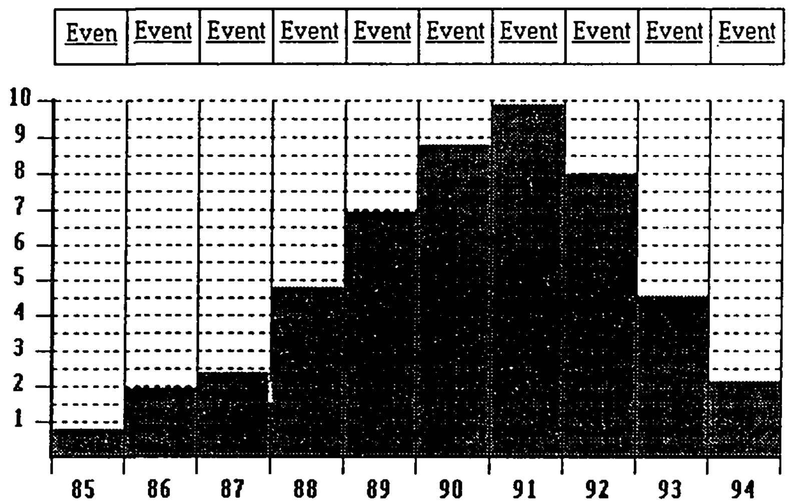
Screen 10:

RETURN TO DATA ENTRY FORM


COMMENTS SCREEN
provided on the Data Entry Screen
Screen 2:
Screen 3:
Screen 4:
Screen 5:
Screen 6:
Screen 7:
Screen 8:
Screen 9:
Screen 10:
RETURN TO DATA ENTRY FORM

DATA ENTRY SCREEN #2 - LAUNCH COSTS

How has the cost per pound of payload mass to LEO
for Expendable Launch Vehicles varied over the past 10 years?



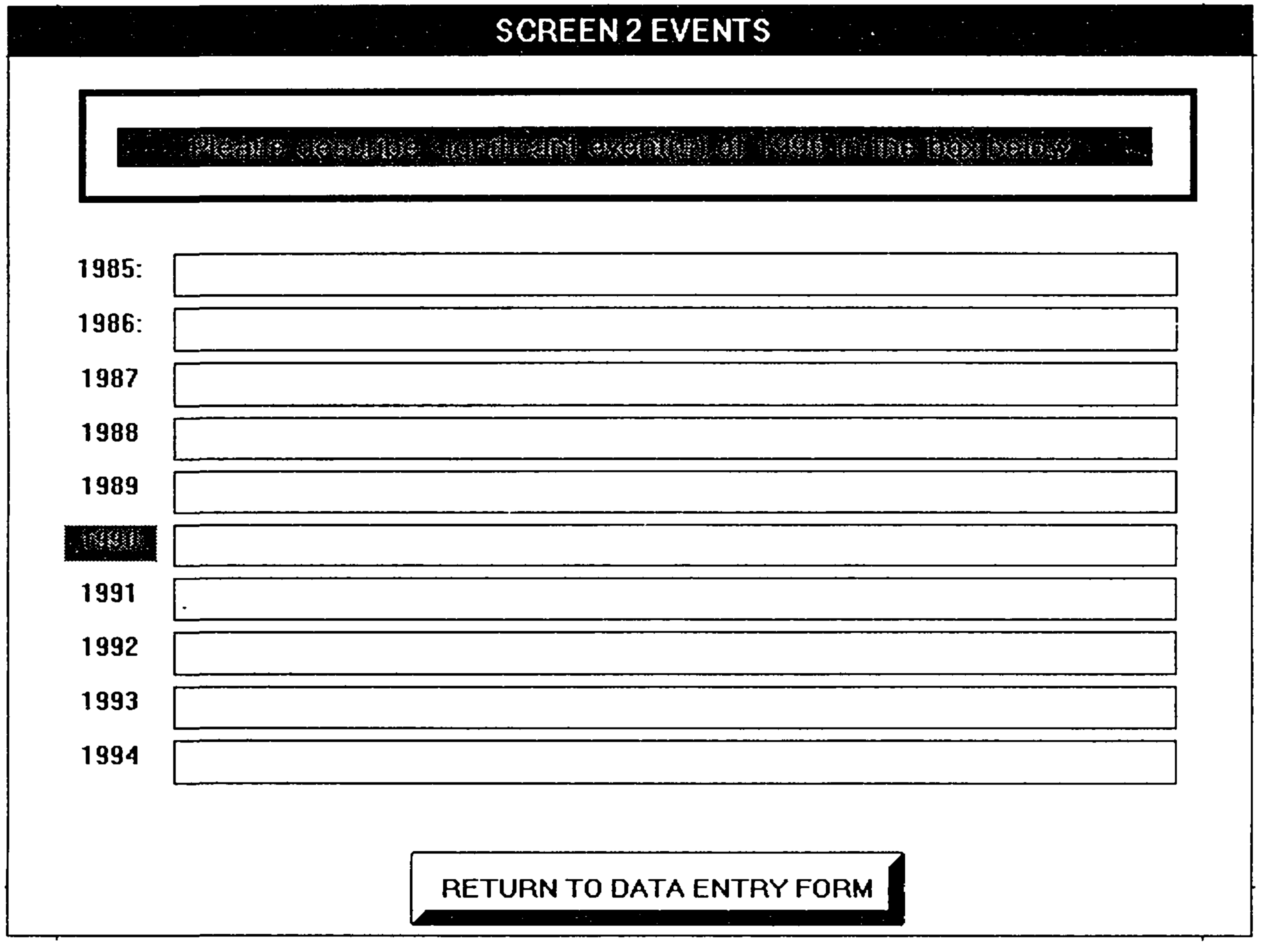
DATA SOURCE

COMMENT

NEXT SCREEN

SELECT SCREEN

QUIT



SCREEN 2 EVENTS

Please describe significant event(s) of 1990 in the box below

1985:

1986:

1987

1988

1989

1990

1991

1992

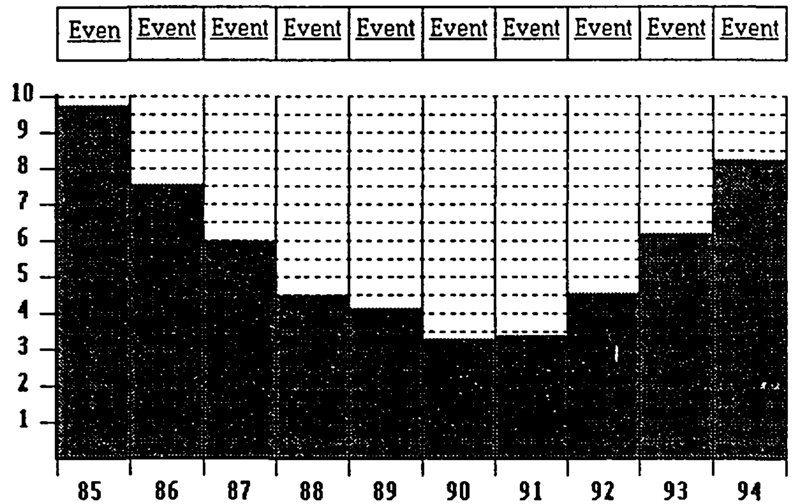
1993

1994

RETURN TO DATA ENTRY FORM

DATA ENTRY SCREEN #3 - REGULATORY ENVIRONMENT

How strongly has the legal/regulatory environment supported commercial space activities over the past 10 years?



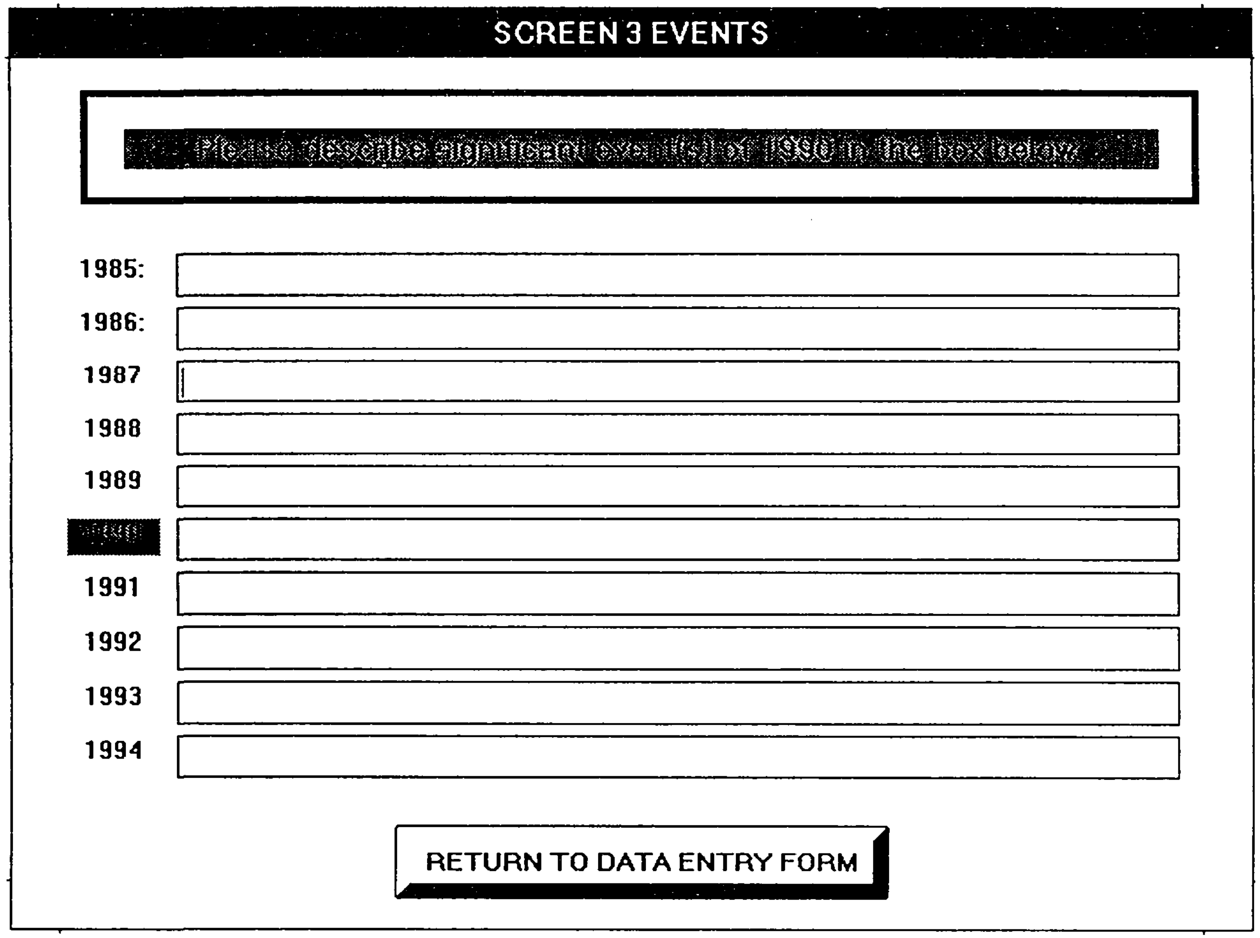
DATA SOURCE

COMMENT

NEXT SCREEN

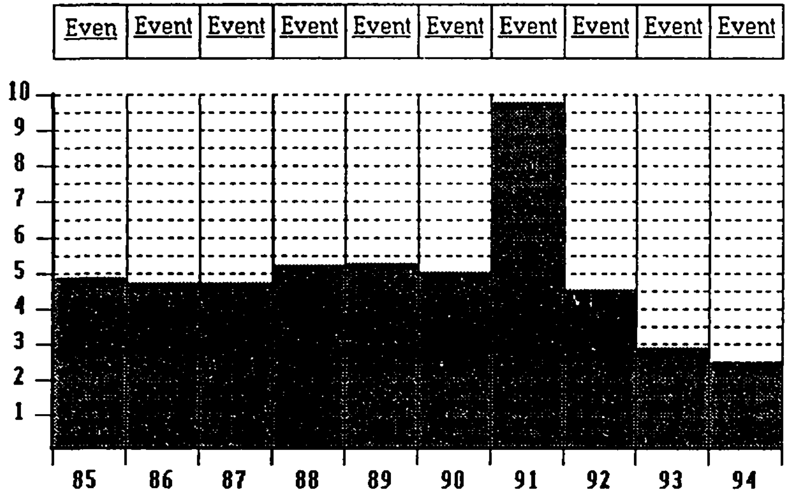
SELECT SCREEN

QUIT


SCREEN 3 EVENTS
Please describe significant event(s) of 1990 in the box below.
1985:
1986:
1987
1988
1989
1990
1991
1992
1993
1994
RETURN TO DATA ENTRY FORM

DATA ENTRY SCREEN #4 - POLITICAL SUPPORT

How strongly has the federal administration supported commercial space activities over the past 10 years?



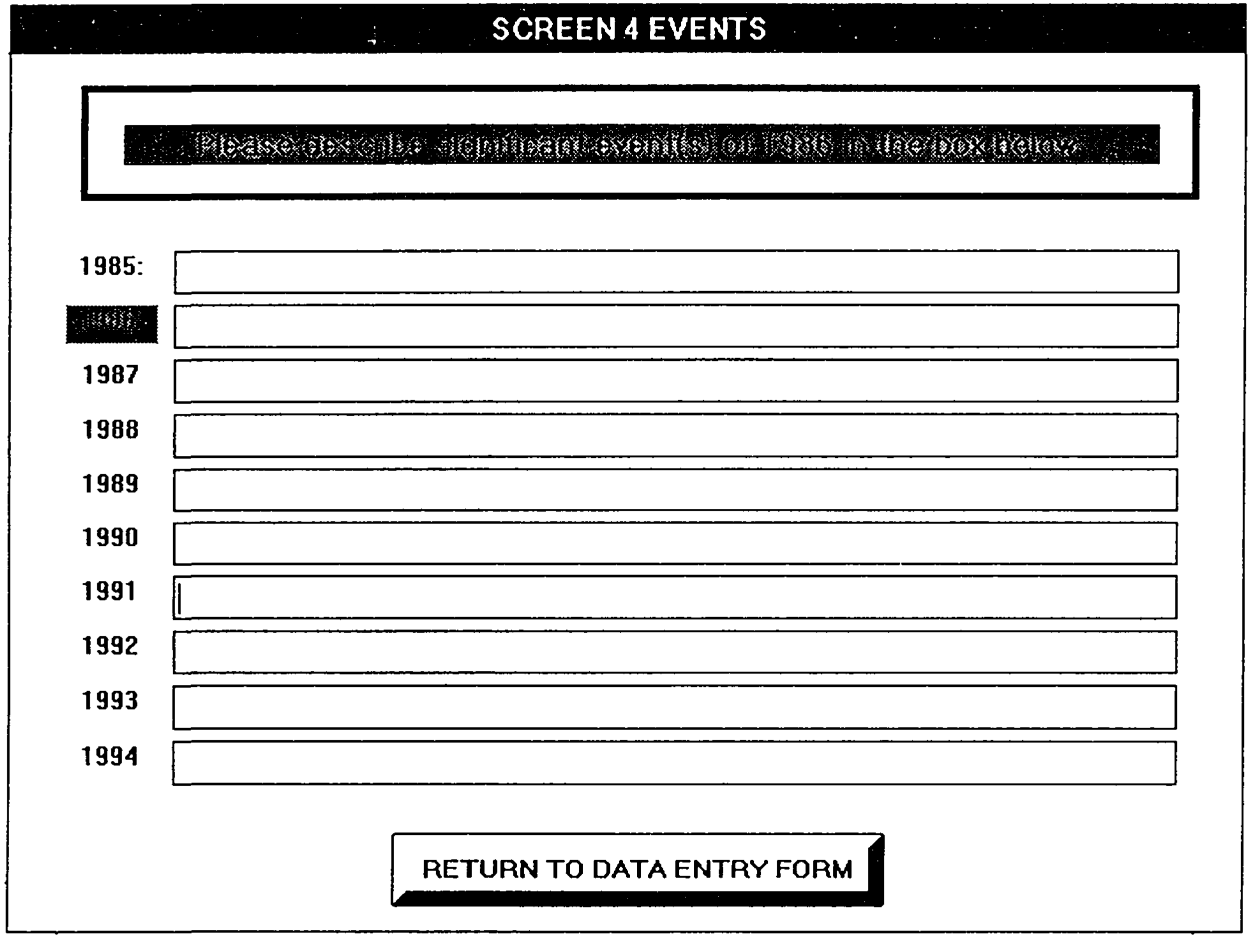
DATA SOURCE

COMMENT

NEXT SCREEN

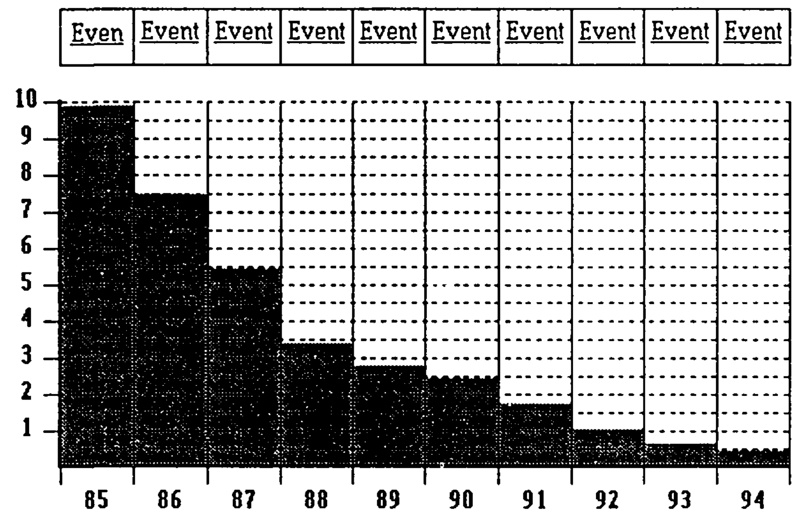
SELECT SCREEN

QUIT


SCREEN 4 EVENTS
Please describe significant event(s) of 1986 in the box below
1985:
1987
1988
1989
1990
1991
1992
1993
1994
RETURN TO DATA ENTRY FORM

DATA ENTRY SCREEN #5 - COMPETITION

What has been the relative level of competition (how many small to mid-sized launch providers world-wide) over the past 10 years?



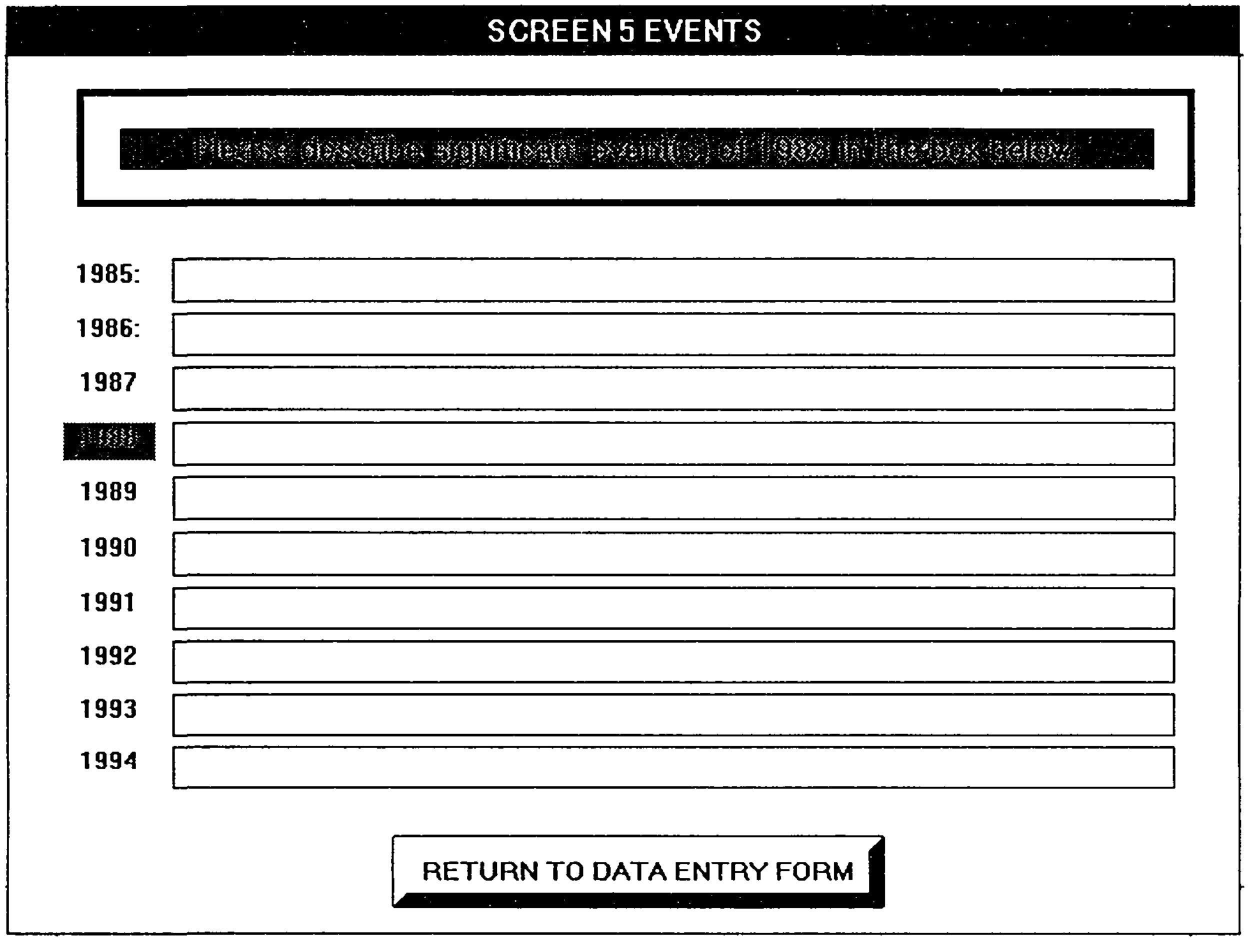
DATA SOURCE

COMMENT

NEXT SCREEN

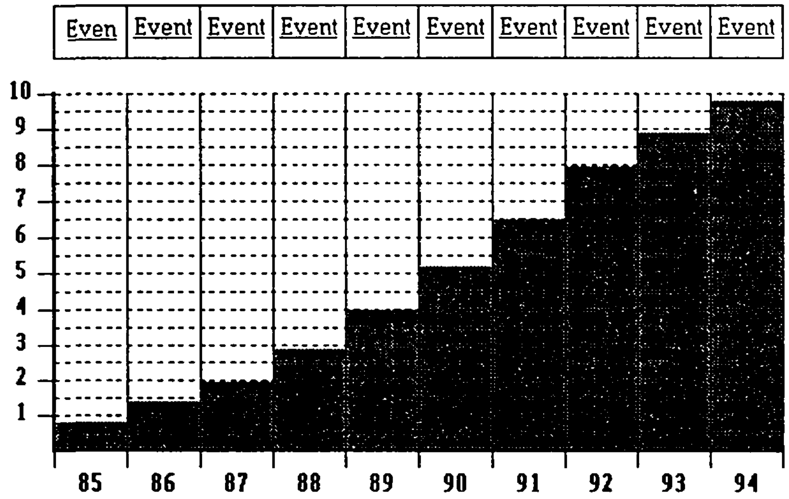
SELECT SCREEN

QUIT


SCREEN 5 EVENTS
Please describe significant event(s) of 1988 in the box below
1985:
1986:
1987
1988
1989
1990
1991
1992
1993
1994
RETURN TO DATA ENTRY FORM

DATA ENTRY SCREEN #6 - TECHNOLOGY

What has been the relative level of new technology introduction for small to mid-sized ELV's and satellites over the past 10 years?



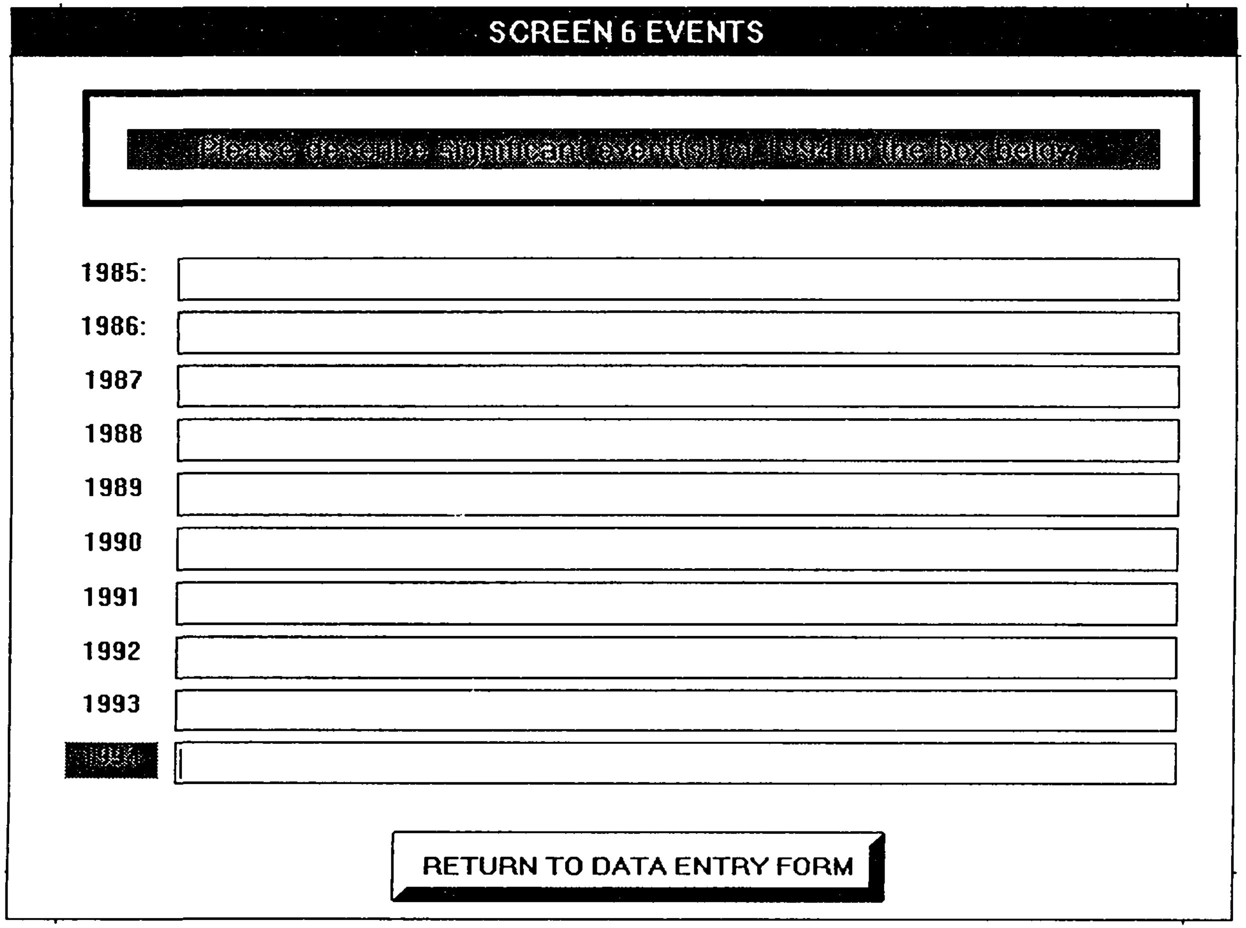
DATA SOURCE

COMMENT

NEXT SCREEN

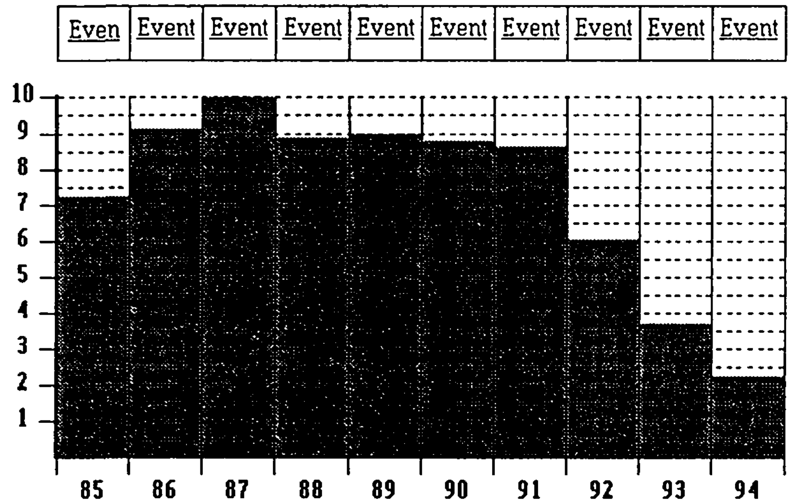
SELECT SCREEN

QUIT


SCREEN 6 EVENTS
Please describe significant event(s) of 1994 in the box below
1985:
1986:
1987
1988
1989
1990
1991
1992
1993
1994
RETURN TO DATA ENTRY FORM

DATA ENTRY SCREEN #7 - PUBLIC OPINION

How supportive of space activities
has the public been over the past 10 years?



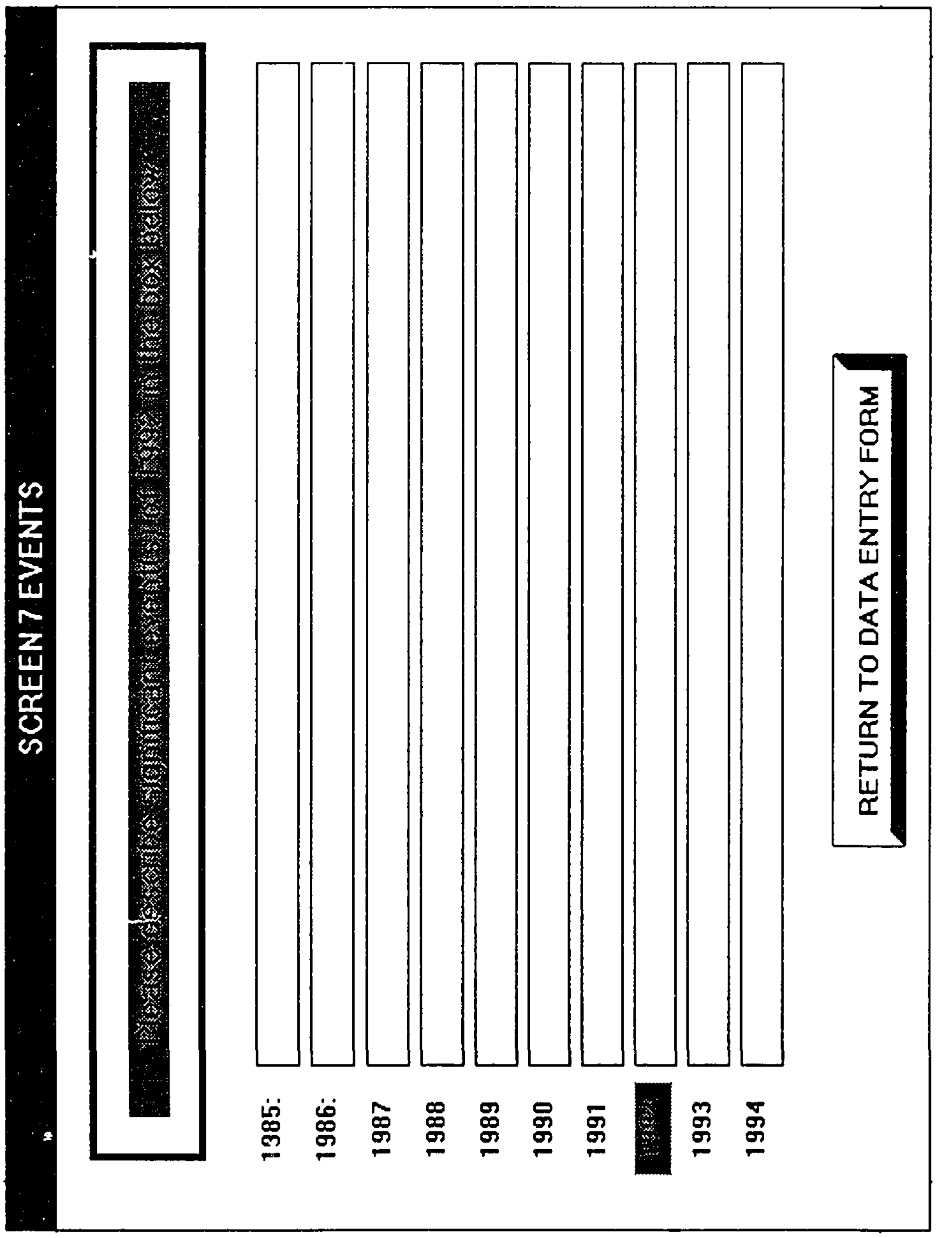
DATA SOURCE

COMMENT

NEXT SCREEN

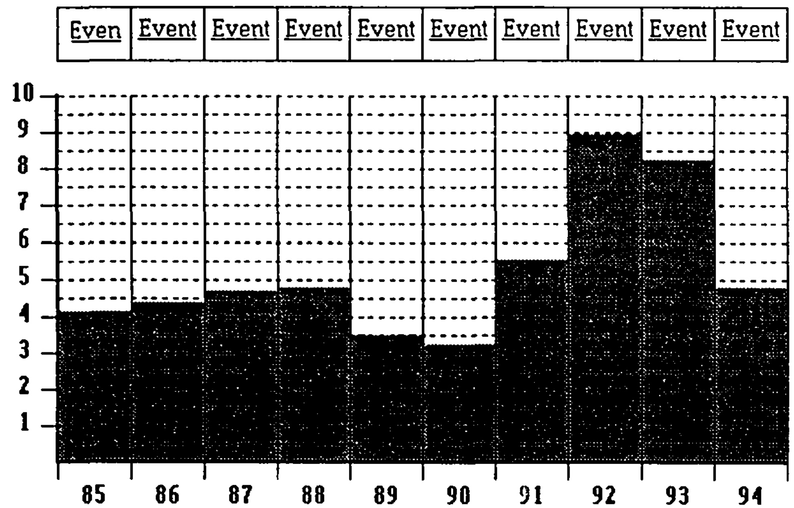
SELECT SCREEN

QUIT


SCREEN 7 EVENTS
Please describe significant events of 1992 in the box below
1985:
1986:
1987
1988
1989
1990
1991
1992
1993
1994
RETURN TO DATA ENTRY FORM

DATA ENTRY SCREEN #8 - ACADEMIC ACTIVITY

What has been the relative level of space-related academic research activity over the past 10 years?



DATA SOURCE

COMMENT

NEXT SCREEN

SELECT SCREEN

QUIT

SCREEN 8 EVENTS

Please describe significant event(s) of 1985 in the box below.

1985:

1986:

1987

1988

1989

1990

1991

1992

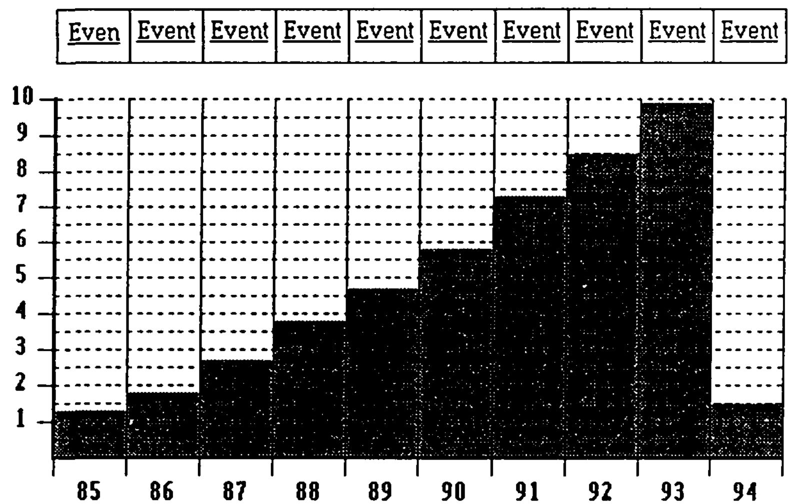
1993

1994

RETURN TO DATA ENTRY FORM

DATA ENTRY SCREEN #9 - NASA SUPPORT

How has NASA's support of commercial space varied over the past 10 years?



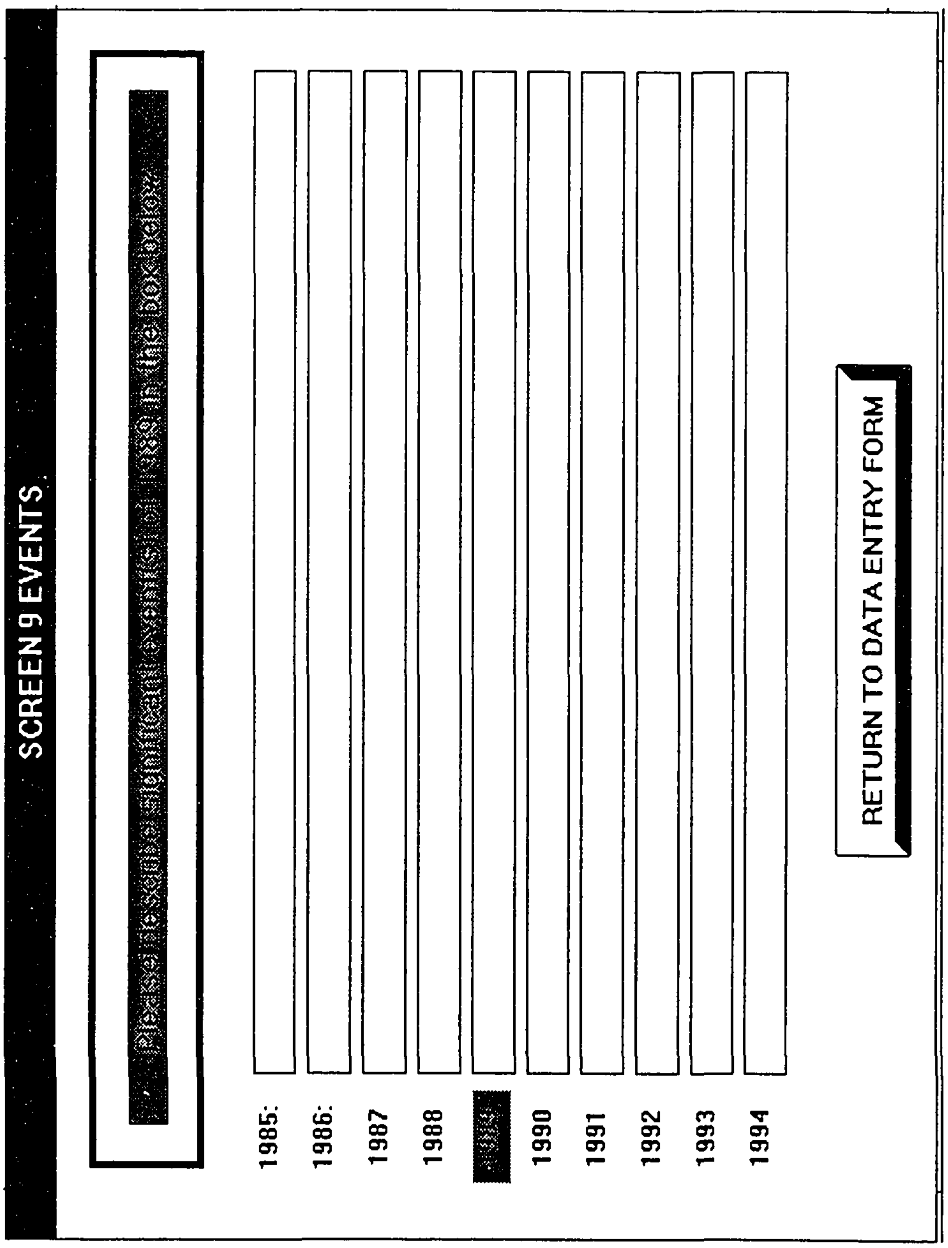
DATA SOURCE

COMMENT

NEXT SCREEN

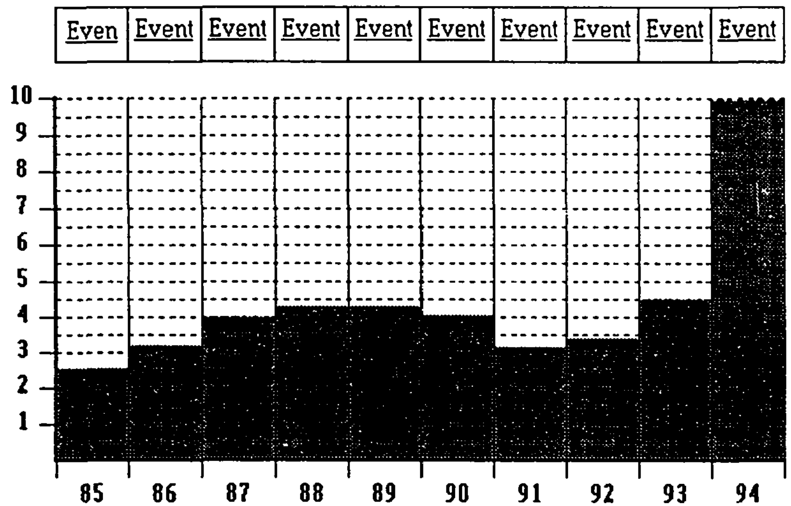
SELECT SCREEN

QUIT


SCREEN 9 EVENTS
Please describe significant event(s) of 1989 in the box below.
1985:
1986:
1987
1988
1989
1990
1991
1992
1993
1994
RETURN TO DATA ENTRY FORM

DATA ENTRY SCREEN #10 - DoD SUPPORT

How has DoD's support of commercial space varied over the past 10 years?



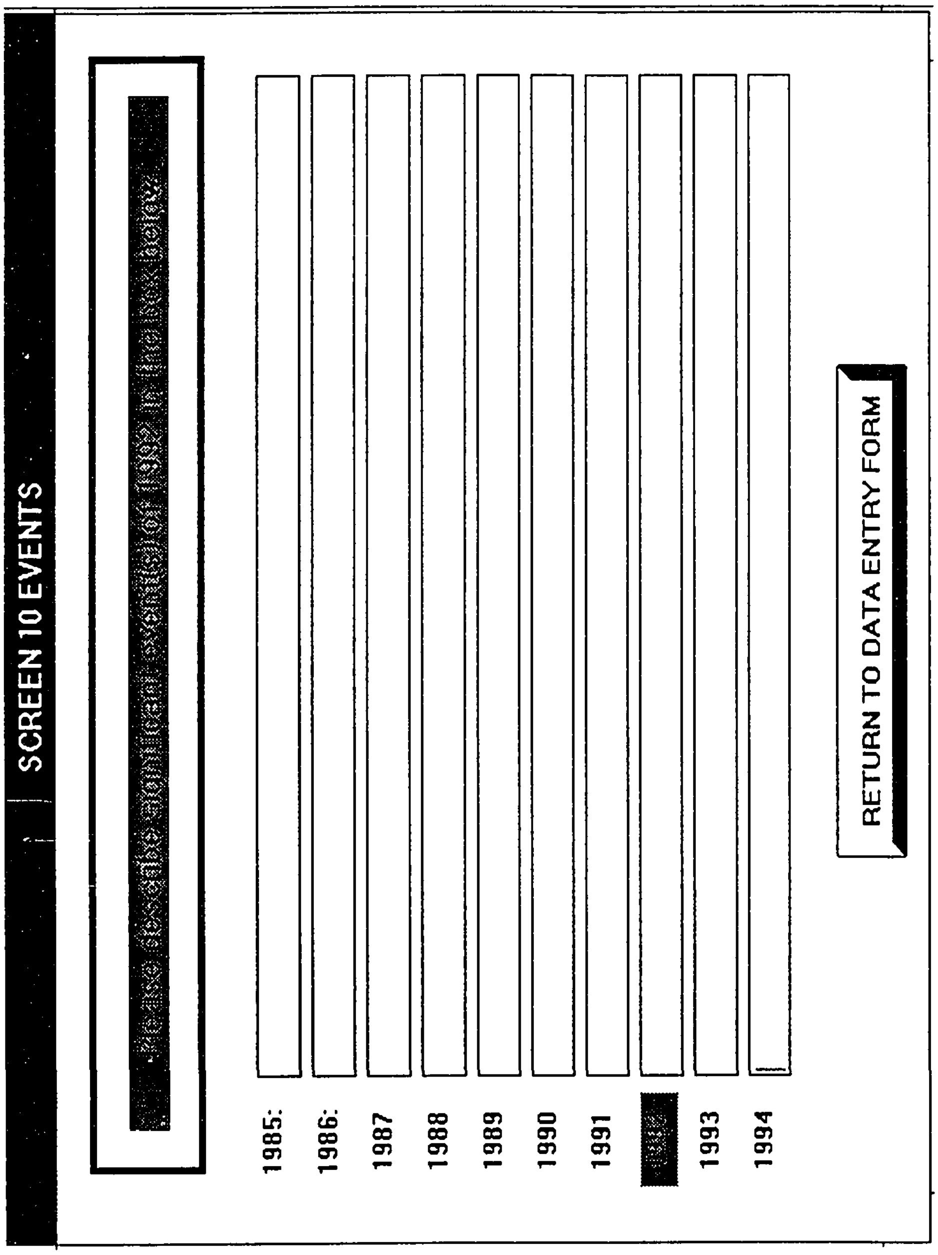
DATA SOURCE

COMMENT

NEXT SCREEN

SELECT SCREEN

QUIT


SCREEN 10 EVENTS
Please describe significant event(s) of 1992 in the box below.
1985:
1986:
1987
1988
1989
1990
1991
1992
1993
1994
RETURN TO DATA ENTRY FORM

DATA ENTRY SCREEN MENU

To make a selection, click on the button to the right of the desired entry screen. If this is your first time through the survey, it is recommended that you proceed sequentially through all of the data screens to determine which of the questions you wish to answer.

Data Entry Screen #1 - Launch Activity ◉

Data Etry Screen #2 - Launch Costs ○

Data Entry Screen #3 - Regulatory Environment ○

Data Entry Screen #4 - Political Support ○

Data Entry Screen #5 - Competition ○

Data Entry Screen #6 - Technology ○

Data Entry Screen #7 - Public Opinion ○

Data Entry Screen #8 - Academic Activity ○

Data Entry Screen #9 - NASA Support ○

Data Entry Screen #10 - DoD Support ○

Summary Comments Screen ○

SUMMARY COMMENTS SCREEN

Please provide any additional comments regarding the survey instrument.
Also use the space below to provide name, address and phone number
[illegible]

This is the last screen in the survey. You can quit or review prior data screen entries.

SELECT SCREEN | QUIT

Space Infrastructure Survey Instructions

Thank you for participating in this survey to support my dissertation research. The objective of the research is to contribute to the body of knowledge in strategic decision making in environments characterized by primary uncertainty and non-linear dynamic relationships. You were selected as a survey respondent because of your knowledge and/or interest in space launch activities. It is not anticipated that you will be able to respond in all ten of the information categories of the survey, but you are encouraged to respond in any area that you have some knowledge. Your responses will be kept confidential. Only aggregate data from all respondents will be presented in the final document.

The enclosed software was custom designed for this survey, using Visual Basic Version 3.0. It requires an IBM-compatible machine with MS-DOS Version 3.1 or later and Microsoft Windows Version 3.0 or later running in standard or enhanced mode. Please note that with older hardware configurations having low processing rates and minimal memory capacity, the execution time for this and other Windows-based software products will increase drastically. If you have any problems running the software, please contact me by phone at the number listed below.

The MS-DOS SHARE.EXE program must also be running. If SHARE is not executed in your AUTOEXEC.BAT file, you must exit Windows and, at the DOS Prompt, type SHARE/L:500 then hit the Enter key, and then restart Windows.

The enclosed floppy diskette contains a "setup" program that will load the SURVEY1 program onto your hard drive and create an icon in the Windows Program Manager. To run the setup program, insert the diskette, start Windows, and use the File Manager to locate the setup.exe program on the floppy drive you are using. Double click your mouse on setup.exe. Setup will make a directory called SURVEY1. It is important that you do not elect to change the directory name.

****

The diskette supplied to you has been screened for all known viruses and none have been detected.

****

To run the program, simply double click on the SURVEY1 icon in the Windows Program Manager, and follow the directions. The program runs in a manner similar to other Windows applications.

A brief tutorial is included in the program. It contains important information which will facilitate your interaction with the software, and ensure the validity of the data you provide. If using the software for the first time, or unsure of how to proceed, please go through this tutorial.

Any time you quit the program, your responses will be saved to a data base resident on the floppy diskette. You can quit and restart as many times as you wish without losing data previously entered.

The final interactive screen in the program is a Summary Comments screen. It is accessed from the final Data Entry screen (No. 10). Any additional comments you have can be entered in text on this screen, and will be greatly appreciated.

When you are finished with the survey, simply return the diskette by mail in the envelope provided. If you wish to keep the software or pass it on to colleagues, additional copies of the diskettes can be made. It is best to copy prior to entering data. (Note that the program will not execute with the diskette removed from the drive.)

Wayne Woodhams
Department of Engineering Management
Old Dominion University
Norfolk, VA 23529

Voice: (804) 683-5478
FAX: (804) 683-5640

APPENDIX C

SOLICITED SURVEY RESPONDENTS

Survey Respondents Solicited, by Position

- Manager, NASA Headquarters Commercial Programs Office
- Assistant Administrator for Commercial Programs, NASA Field Activity
- Former NASA Launch Vehicle Development Program Manager
- Director, Space Communications Technology Center
- Associate Director, U.S. DoT Office of Commercial Space Transportation
- Legislative Assistant for Space, U.S. Congress, Science, Space and Technology Committee
- Policy Analyst, White House Office of Science and Technology Policy
- Launch Vehicle Program Manager, Large Aerospace Conglomerate
- Senior Mechanical Engineer, Launch Vehicle Division, Mid-Sized Launch Vehicle and Satellite Developer
- Business Development Manager, Commercial Communications Satellite Developer
- Systems Engineer, Commercial Space Hardware and Services Provider
- Former General Manager of (Aerospace)Technology Transfer, State Government Agency
- Director, State-Sponsored Spaceport Activity
- Attorney At Law, Specializing in Space Law
- Manager, Space Investment Group
- Director, Academic Space Research Association
- Director, Space Grant Consortium
- Editor, Space Periodical
- Director, Student Programs, Aerospace Professional Association
- Space Policy Analyst
- Commercial Space Insurance Underwriter

APPENDIX D

RAW RESPONDENT DATA

Respondent N-4-1

Question	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	1.375	1.5	1.1875	1.5	1.25	1.75	1.75	3.875	10	5.5625
2	7.75	8.0625	8.5	8.75	8.9375	9.25	9.375	9.5625	9.5	10
3	6	6.125	6.625	7.5	8.5	9.5	10	9.0625	7.5	5.5
4	6.75	7.625	8.0625	8.75	9.1875	9.5	10	9.875	8	4
5	2.9375	2.9375	3	2.9375	5.9375	7.6875	8.6875	8.9375	9.25	10.0625
6	1.9375	4.5	6	7.5	8.3125	8.6875	9.9375	10	9.75	9.625
7	8.5625	8.4375	8.5625	8.9375	9.1875	9.1875	9.25	10.0625	10	10
8	8.4375	8.75	9	9.1875	9.1875	9.5625	9.9375	9.9375	8.6875	7.5625
9	4.9375	7.375	8.5	9.0625	9.5	10.0625	9.625	8.5625	6.5	1.5
10	0.5625	0.4375	0.375	0.4375	0.625	0.4375	0.375	2.4375	6.5	10.0625

Data Sources

Screen 1: "None - just guesses "

Screen Comments

Screen 1: "Low end # confined to Scout until Pegasus, upper end # was Delta & Atlas"

Screen 2: "Little change since there were limited customers - curve should match inflation"

Screen 3: "DOT is the big player, they restricted their views to launch only until COMET"

Screen 6: "DOD didn't need small vehicles until $ crunch occurred, NASA just figured it out in '94"

Screen 7: "Visited NASA & DOD visitors centers all over the country - I've always found them crowded!"

Screen 10: "In a declining DOD budget, COMSPACE is now a potential source of income for DOD - strongly supported now."

"Summary Comments"

"Wayne, glad to help. These are my first guesses, backed up by experience but no data. The launch rates are a matter of record and are carried in Jane's and the AIAA magazine, I just don't have the actual numbers handy. Hope my submission is a bit of help. Should you wish me to go back and dig up data to back up my assertions and "hip shots", let me know, I may have a bit more time in early March. It's interesting that you took such a wide payload weight, there have been launchers to service the upper weight needs but, when we started COMET, there were NO launchers on the market which were targeted for the 2000# bracket - if there were, we would have bought three!"

Good luck and let me know if I can be of any further help.

Respondent S-1-1

Question	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	2.9375	2.9375	2.8125	3.5625	4.25	4.4375	4.1875	4.1875	4	3.875
2	4.9375	4.8125	4.75	4.9375	5.3125	5.5625	5.8125	5.75	6.25	6.6875
3	7.125	6.8125	6.25	5.875	6.125	6.4375	6.9375	5.875	4	2.5
4	4.0625	3.875	3.875	3.625	3.125	2.4375	1.8125	1.125	1	1.0625
5	2.0625	2.0625	2.125	1.9375	2.4375	2.6875	3.125	3.4375	3.3125	3.3125
6	1.0625	1.125	1.125	1.25	6.4375	4.0625	3.4375	6.1875	7.3125	8.1875
7	5	8.25	5.5625	5.375	4.875	4.375	4.25	2.6875	2.4375	2.625
8	7	6.9375	7.0625	6.875	6.125	5.1875	4.6875	4.4375	3.6875	3.5
9	3.0625	3.625	4.0625	3.75	3.1875	2.5625	2.1875	1.6875	1.25	0.9375
10	1.75	1.625	2.3125	3	3.75	3.625	3.6875	4.0625	4.25	4.875

Screen 6 Events

1989: "Introduction of Pegasus"

Screen Comments

Screen 3: "The changes of administration and space policy has affected Commercial Space. As Congress has grappled with remote sensing and launch vehicle issues, the support for Commercial Space has changed."

Screen 8: "Falloff of research due to SDI reduction and military reduction levels "

Respondent N-4-2

Question	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	-0.0625	-0.0625	-0.0625	0	0	0.125	0	0.0625	0.125	-0.0625
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0
9	8	8	8.0625	7.9375	8.0625	8	4	2.8125	2.8125	1.9375
10	0	0	0	0	0	0	0	0	0	0

Screen 4 Events

1986: "Established CCDS program"

1993: "CCDS Program Cut"

1994: "CCDS Program severely cut"

Screen 9 Events

1985: "Supported CCDS effort"

1986: "Supported CCDS effort"

1987: "Supported CCDS effort"

1988: "Supported CCDS effort"

1989: " Supported CCDS effort"

1990: "Reorganization placed CCDS program in jeopardy"

1991: "NASA's continued reorganization jeopardized CCDS program"

1992: "NASA's continued reorganization jeopardized CCDS program"

1993: "Cutbacks, reduced funding of CCDS program, number CCDSs reduced"

1994: "NASA reorganization, cutbacks, CCDS program in jeopardy"

Screen 10 Events

1993: "TRP - good for commercial space (ARPA)"

1994: "TRP - good for commercial space (ARPA)"

Respondent N-4-2 (Cont'd.)

Screen Comments

Screen 10: "Good until Challenger. Bad after Challenger accident. Bad now. "

Respondent L-1-1

Question	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	1.75	2.1875	0.8125	1.1875	1.25	0.6875	1.3125	0.6875	0.8125	0.5
2	0	0	0	0	0	0	0	0	0	0
3	1.75	1.625	1.5625	2.3125	2.125	2.6875	2.6875	3.1875	3.3125	3
4	3.6875	3.5	3.4375	5.3125	3.3125	3.3125	3.125	3.125	3.125	3.9375
5	4.9375	4.9375	4.875	4.8125	6	6	5.9375	5.9375	6	5.9375
6	1.9375	1.75	1.8125	1.8125	2	1.8125	1.875	1.875	1.8125	1.875
7	4.9375	5.9375	4.8125	3.9375	2.875	2.5	2.5	2.5	2.4375	2.4375
8	0	0	0	0	0	0	0	0	0	0
9	1.875	1.9375	1.8125	2.375	2.375	1.8125	1.875	1.8125	1.8125	1.75
10	0.375	0.4375	0.375	0.6875	1.125	1.3125	1.75	1.875	2.4375	3

Summary Comments

"(Contact), DOT/OCST, (202) 366-2980"

Respondent G-1-1

Question	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	0	0	0	0	2.75	6.625	6.8125	5.5625	4.1875	4.125
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	7.9375	5.4375	7.875	7.9375	7.875	7.8125
4	0	0	0	0	0	3.5625	3	2.875	4.3125	4.3125
5	0	0	0	0	0	4.625	6.1875	4.9375	7.9375	8.9375
6	0	0	0	0	4.9375	4.9375	4.9375	5.8125	6.9375	7.875
7	6.75	3.8125	3.5	3.1875	3.1875	3.125	3.0625	2.875	2.8125	2.5625
8	0	0	0	0	0	0	0	0	0	0
9	2	1.8125	2.875	1.875	1.8125	0.875	0.875	1.875	3.875	5
10	1	1	0.875	1.875	1.9375	1.375	1.25	1.25	2.875	6.375

Data Sources:

Screen 1: "Office records on commercial licensed launches"

Screen 2: "anecdotal "

Screen 3: "personal observation"

Screen 4: "personal observation"

Screen 5: "market studies, observation"

Screen 9: "personal observation, NASA statements"

Comments Screens

Screen 1: "only dealing with commercial licensed launches since first in 1989"

Screen 2: "incremental improvements in existing vehicles has brought some savings"

Screen 3: "1990 drop represents NASA taking their launches out of commercial "

Screen 4: "support has been mostly verbal, little action "

Screen 5: "new countries, new vehicles entering market "

Screen 8: "I don't really have much idea "

Screen 9: "marked change under Dan Goldin and budget pressure"

Screen 10: "they seem to have realized that post-cold war, commercial is wave of future "

Respondent C-2-1

Question	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	7	1.9375	1.8125	2.4375	2.9375	4.375	4.6875	5.4375	6.0625	6.125
2	2.3125	2.125	1.8125	1.375	1.1875	1.3125	1.125	1.1875	1.5625	1.75
3	2	1.9375	5.4375	6.4375	6.25	6.3125	6.1875	6.875	7.625	8.4375
4	2.0625	2	2.5625	2.625	2.625	2.75	2.9375	4.25	4.5	5.0625
5	0.9375	0.875	1.4375	2.1875	3.0625	5.125	7	5.9375	5.5625	5.0625
6	1.0625	1.0625	0.9375	3	3.9375	4.5625	4.875	5.25	5.5	5.875
7	6.0625	5.5	3	2.625	2.25	1.8125	1.6875	1.6875	1.5625	1.6875
8	5.9375	1.1875	1.1875	1.1875	1.5	1.875	2.1875	2.5625	2.875	3.4375
9	4	0.9375	1	0.9375	0.9375	1.0625	1.1875	1.3125	1.375	1.375
10	1.875	1.8125	3	3.3125	3.5625	3.6875	4.0625	4.1875	4.4375	4.5625

Data Source Comments:

Screen 3:

"With the advent of the WARC and FCC "opening" of the radio spectrum, and the loosening of the DoD restrictions on use of hi-res imagery, the regulatory environment is vastly improved."

Screen Comments

Screen 1:

"A lot of "small spacecraft" were effectively carried into orbit via the shuttle, prior to Challenger. The attached payloads program has been a low-level-of-effort, but successful NASA program -- one of the very few bright spots in the NASA commercial mix."

Screen 2:

"This varies significantly for secondary vs. dedicated launch costs. Secondary costs are very low; dedicated launcher costs have stabilized at or around $10-15 million per launch, less with Russian rockets. Big problem today is cost of launch insurance - a significant portion of the total mission cost!"

Screen 3:

"With the advent of the WARC and FCC rules for Big and Little LEOs, and the lifting of restrictions on hi-res imagery, regulatory issues support commercial space are extremely favorable today."

Screen 4:

" Federal policy moved from "benign neglect" in the early 80s, to one of strong support. Support came mostly from DARPA and FCC, not NASA. In general, NASA remains hostile to commercial space, and small space in particular. Note how many missions, like Clementine, Big and Little LEOs are completely devoid of NASA support. To NASA, commercial space remains materials processing and spin-offs, and maybe ACTS, too. Note how NASA screwed up the COMET program."

Respondent C-2-1 (Cont'd.)

Screen 5:

" *First, there was only shuttle and Ariane. Then came a bunch of "non-real" companies,* like E-Prime. Then OSC with Pegasus and Taurus, followed by International MicroSpace, Ariane ASAP ring, and growth in large commercial rockets, entry of China. With fall of Soviet Union, Russian rockets became available, and big companies entered the fray, such as Lockheed, with LLV and the LKE. Then, a few drop-outs, like CTA (bought, then discarded International MicroSpace), Conatech, EER, and others. There are now only a few small satellite launch services providers, but the credibility of the remaining players is pretty good."

Screen 6:

"Many new and innovative technologies have been developed in support of small space. The Pegasus design used many new approaches, including synthetic wing and highly automated booster manufacture. Many advances have also found there way into the spacecraft, such as Orbcomm small batteries, STARSYS advanced CDMA communications filter, and others, enabling smaller and small payloads to be very, very capable."

Screen 7:

"Following the Challenger disaster, the public's support of "space" has become almost non-existent. However, despite this era of budget-cutting worldwide, allowed by public apathy in gov't space programs, industry has re-awakened to see many possibilities in communications and hi-resolution remote sensing."

Screen 8:

"Academic space research of a commercial nature, is making a slow but steady recovery from the Challenger disaster. It takes years for academic projects to be decided upon and funded. Also, since business in pursuing commercial space activity more vigorously than gov't, that is "where the action is," and business-university relationships for R&D are precarious, at best, and often aren't fruitful for the company."

Screen 9:

"NASA's disdain for the commercial space community can be best seen in the abolishment of "Code C," the office of commercial programs, and in NASA's constant turf wars with other Federal commercial space operations (DoT, DoC, and others). NASA has completely bungled the relationship with industry vis-a-vis the Space Station. The only truly viable NASA commercial programs going on today are ACTS and some remote sensing work, although the latter is benefiting primarily from the declassification of DoD missions. Also, NASA is testing out some commercial use of TDRSS. NASA, by and large, thinks that "spin-offs" are commercial space, and the agency is more interested in protecting and administering its operational programs, rather than in fostering the development of a strong industry."

Respondent C-2-1 (Cont'd.)

Screen 10:

" DoD has learned that the commercial industry can be a true friend and a reliable supplier of high-tech solutions to DoD needs. After the Challenger disaster, DoD was effectively "forced" to rely upon the industry for ELVs, a policy which has been very successful. Also, almost in an accidental partnership, a DoD mission - GPS - has spawned a multi-billion dollar positioning industry. (Also, remember when the Internet was 'ARPANET?') DoD is interested in using space to complete its mission, which is military. Therefore, they view space as a "tool" not a "territory." Contrast this with NASA whose mission is space - and therefor, its "turf" is space! Thus, NASA has a "not-invented-here" syndrome, while DoD has a "hey-that's-great-can-I-buy-some-to-complete-my-mission" mentality."

Events: Screen 1

1985: "Space Shuttles carry many attached small payloads into orbit."

1986: "Challenger disaster effectively cripples commercial space industry."

1987: " Resurgence of interest in small payloads, small launch vehicles."

1988: "Spaceport Florida created; OSC announces Pegasus project."

1989: "Spaceport concept spreads to other states (HI, VA, AK); Little LEOs started."

1990: "DARPA buys its first Pegasus; small satellite programs funded by gov't."

1991: "First Pegasus launched; Orbcomm-X launched (failed); Iridium announced."

1992: "Further Big LEO announcements; LLV born; Taurus unveiled; WARC-92."

1993: "Teledesic announced; market becomes clearer for LEO services."

1994: "Orbcomm licensed; second round of Little LEOs nets five applicants."

Events: Screen 3

1985: "Commercial space largely still a "dream," except for GEO communication satellites. "

1986: "Challenger disaster effectively freezes all policy making."

1987: ""No commercial use of shuttle" reinvigorates ELV industry; industry still reeling, however."

1988: "Industry doing "due diligence.""

1989: "Orbcomm, Pegasus, and other initiatives "heat up" the industry."

Respondent C-2-1 (Cont'd.)

1990: "Strong support of small satellites by DARPA."

1991: "Big LEOs, backed by Big Companies, spur interest."

1992: "WARC-92 clears the way for Big and Little LEOs."

1993: "More and more people entering the fray."

1994: "Little LEOs licensed."

Respondent I-1-1

Question	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	9.9375	3.0625	2.5	7	4.5625	10.0625	8.0625	9.5	6	10
2	0	0	0	0	0	0	0	0	0	0
3	6.8125	8	7.875	7.9375	7.9375	8.4375	9.3125	10	9.3125	9.0625
4	8	7.875	8.3125	8.875	9.5	9.9375	9.9375	9.875	9.3125	8.375
5	5.125	4.9375	5.9375	6.875	7.5	7.4375	8.0625	8.9375	9.5	10.0625
6	6.875	7.375	7.9375	8.9375	7.875	8.5	8.5	8.9375	10	10.0625
7	9.875	9.875	8.9375	7.75	6.875	6.3125	6.125	5.6875	5.625	5.5625
8	0	0	0	0	0	0	0	0	0	0
9	9.9375	9.0625	5.5	5.5	6	6.375	6.5	6.5	6.75	6.875
10	9.9375	10	9.875	9.8125	9.9375	9.9375	9.9375	9.875	10	9.875

Data Sources:

Screen 1: "COMMERCIAL GEOSYNCHRONOUS COMMUNICATIONS SATELLITES"

Screen Comments:

Screen 1: "WE DON'T HAVE DATA FOR THE CATEGORIES YOU REQUESTED"

Screen 2: "NOT AVAILABLE IN OUR DATA BASE. CONTACT DEPT OF TRANSP, OFFICE OF COMMERCIAL SPACE TRANSPORTATION 202-366-5770"

Screen 7: "CHALLENGER ACCIDENT IN 1986 HAD SIGNIFICANT IMPACT"

Screen 8: "HAVE NO IDEA "

Screen 9: "AFTER CHALLENGER ACCIDENT, POLICY TO RESTRICT COMMERCIAL PAYLOADS ON SHUTTLE HAD MAJOR IMPACT"

Screen 10: "DOD SUPPORT SEEMS TO BE RESTRICTED TO SUPPORTING A LAUNCH AND SATELLITE INDUSTRY THROUGH THEIR MILITARY CONTRACTS AND SUPPORT OF THE LAUNCH INFRASTRUCTURE. PROCUREMENT OF UFO SATELLITE BY NAVY A MAJOR CHANGE IN APPROACH. NASA'S RECENT AWARD OF TDRS CONTRACT AS A DELIVERY-ON-ORBIT ALSO SUPPORTIVE OF COMMERCIAL SPACE."

Summary Comments

"RESPONSES PROVIDED ON THE BASIS OF NOT BEING ATTRIBUTED TO XXXXXXX OR TO XXXXXX. MUCH OF THIS SURVEY DEALS IN PERCEPTIONS RATHER THAN QUANTITATIVE DATA."

Respondent A-3-1

Question	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
1	0	1	1.25	2	2	3.0625	5.375	7.5	8.3125	8.5625
2	8	7.8125	7.3125	7	6.5	6.375	6.1875	6.3125	6.3125	6.125
3	0.6875	1.0625	2	2.0625	3.5625	3.8125	5.625	5.875	5.9375	6.9375
4	0.875	2.25	2.25	2.3125	7	7	7	8.0625	8.0625	8
5	3.625	3.625	4.875	4.8125	5.9375	8.5	8.5625	8.5	10.0625	10
6	4.1875	3.9375	5.5	5.5	7.875	7.8125	7.9375	10	10	10
7	9.8125	8.3125	7.5	6.5	6.0625	5.5625	4.8125	4.75	4.75	4.0625
8	9.625	8.5	7.6875	8.5	8.4375	8.625	8.375	7.5625	7.5625	6.5625
9	0.6875	0.5625	0.5625	1.0625	1.25	1.5625	1.5	1.9375	2.0625	2
10	1.9375	1.9375	2.5625	2.5	3	4	4.0625	4.0625	4.5	4.5625

Summary Comments

"My responses are not data based but are based on perspectives and impressions from working in the aerospace arena since 1979. I am more familiar with NASA programs than those of DOD and I am sure that this is reflected in my responses."

APPENDIX E

RATIONALE AND DATA FOR FILTERED MARGINAL CHANGE DATA

Data Filtering Rationale by Decision Factor

Factor No. 1: Launch Activity

'85 - '86: There is disagreement in the data. Two respondents indicated a precipitous decrease while the others indicated a small increase. Ancillary data supports the decrease due to the Challenger accident in 1986. Prior to Challenger, the space shuttle carried many small to mid-sized payloads to orbit. The other data were unsubstantiated.

'86 - '87: There was a consensus on a modest decline. No outliers.

'87 - '88: There was consensus on a modest increase, with one outlier suggesting a large increase. Comments made by the outlier indicated that the response was based solely on geosynchronous communications satellites. The level of increase would be inaccurate since this type represents only a small portion of the total launch activity. The response was discarded.

'88 - '89: There was no consensus. One substantial increase was indicated, as well as a substantial decrease. The decrease was from the same outlier as noted for '87 - '88. The increase was based on commercial launch activity only, and probably overstated. Since they nearly offset, both were retained.

'89 - '90: There was a consensus on a substantial increase. Comments indicate that small satellite launches started being funded by the government. One outlier may overstate the increase somewhat, but no evidence existed for its deletion.

'90 - '91: There was no consensus. One substantial increase was indicated, as well as a substantial decrease. Both were retained.

'91 - '92: There was no consensus, and no outliers. No evidence for deletion of any responses.

'92 - '93: There was no consensus. There was one large positive outlier, and one fairly large negative. No evidence was given to refute either, so both were retained.

'93 - '94: There was no consensus. There was one positive and one negative outlier. The positive one was based on only part of the market. The negative one had no supporting data. Both were retained.

Factor No. 2: Launch Costs

'85 - '86: Consensus on slight decline. No outliers.

'86 - '87: Consensus on slight decline. No outliers.

'87 - '88: No consensus. No outliers.

'88 - '89: No consensus. No outliers.

'89 - '90: Consensus on slight increase. No outliers.

Factor No. 2: Launch Costs (Cont'd.)

'90 - '91: No consensus. No outliers.

'91 - '92: Consensus on slight increase. No outliers.

'92 - '93: No consensus. No outliers.

'93 - '94: Consensus on slight increase. No outliers.

Factor No. 3: Legal/Regulatory Environment

'85 - '86: No consensus. No outliers.

'86 - '87: No consensus. One positive outlier, substantiated by ancillary data which identified the unfreezing of policy making which was curtailed following Challenger. The response was retained.

'87 - '88: Consensus on slight increase. No outliers.

'88 - '89: No consensus. One highly positive outlier, with the comment that data is based on personal observation. The data indicate that this was the first year for which the respondent had information or knowledge, and all prior years were entered as zero. The response was discarded, since it did not represent a change in the factor.

'89 - '90: Consensus on slight increase. No outliers.

'90 - '91: Consensus on increase. No outliers.

'91 - '92: No consensus. No outliers.

'92 - '93: No consensus. No outliers.

'93 - '94: No consensus. No outliers.

Factor No. 4: Support of Federal Administration

'85 - '86: No consensus. No outliers.

'86 - '87: Consensus on slight increase. No outliers.

'87 - '88: Consensus on slight increase. No outliers.

'88 - '89: No consensus. One positive outlier, with no evidence to confirm or deny. Response is retained.

'89 - '90: Consensus on increase, with one positive outlier. The data indicate that this was the first year for which the respondent had information or knowledge, and all prior years were entered as zero. The response was discarded, since it did not represent a change in the factor.

Factor No. 4: Support of Federal Administration (Cont'd.)

'90 - '91: No consensus. No outliers.

'91 - '92: No consensus. No outliers.

'92 - '93: No consensus. No outliers.

'93 - '94: No consensus. One negative outlier, with no evidence to confirm or deny. Response is retained.

Factor No. 5: Competition

'85 - '86: Consensus on slight decrease. No outliers.

'86 - '87: Consensus on increase. No outliers.

'87 - '88: No consensus. No outliers.

'88 - '89: Consensus on substantial increase. No outliers.

'89 - '90: Consensus on substantial increase, with one positive outlier. The data indicate that this was the first year for which the respondent had information or knowledge, and all prior years were entered as zero. The response was discarded, since it did not represent a change in the factor.

'90 - '91: Consensus on substantial increase. No outliers.

'91 - '92: No consensus. No outliers.

'92 - '93: No consensus, one positive outlier. Associated comment indicated that data were a result of market studies. Response retained.

'93 - '94: No consensus. No outliers.

Factor No. 6: New Technology Introduction

'85 - '86: No consensus. No outliers.

'86 - '87: Consensus on increase. No outliers.

'87 - '88: Consensus on increase. No outliers.

'88 - '89: Consensus on substantial increase, with two positive outliers. Ancillary information for one designated introduction of Pegasus launch vehicle as a leap in technology. It was retained. For the other, the data indicate that this was the first year for which the respondent had information or knowledge, and all prior years were entered as zero. The response was discarded, since it did not represent a change in the factor.

Factor No. 6: New Technology Introduction (Cont'd.)

'89 - '90: No consensus. One negative outlier, with no evidence to confirm or deny. Response is retained.

'90 - '91: Consensus on increase. No outliers.

'91 - '92: Consensus on increase. No outliers.

'92 - '93: No consensus. No outliers.

'93 - '94: Consensus on increase. No outliers.

Factor No. 7: Public Support

'85 - '86: No Consensus. One positive and one negative outlier, neither with confirming or denying data. Both responses retained.

'86 - '87: Consensus on decrease. No outliers.

'87 - '88: Consensus on decrease. No outliers.

'88 - '89: Consensus on decrease. No outliers.

'89 - '90: Consensus on decrease. No outliers.

'90 - '91: Consensus on decrease. No outliers.

'91 - '92: Consensus on decrease. No outliers.

'92 - '93: Consensus on decrease. No outliers.

'93 - '94: No consensus. No outliers.

Factor No. 8: Academic Research

'85 - '86: Consensus on decrease, with one negative outlier. Comment stated that research suffered drastically as a result of Challenger. Response retained.

'86 - '87: No consensus. No outliers.

'87 - '88: No consensus. No outliers.

'88 - '89: No consensus. No outliers.

'89 - '90: Consensus on increase. No outliers.

'90 - '91: No consensus. No outliers.

Factor No. 8: Academic Research (Cont'd.)

'91 - '92: No consensus. No outliers.

'92 - '93: No consensus. No outliers.

'93 - '94: Consensus on decrease. No outliers.

Factor No. 9: NASA Support

'85 - '86: No consensus. One negative outlier, supported by comment that NASA has always disdained the commercial space industry. One positive outlier, with no confirming of denying data. Both responses retained.

'86 - '87: No consensus. One negative outlier, supported by comment that Challenger had a deleterious effect.

'87 - '88: No consensus. No outliers.

'88 - '89: No consensus. No outliers.

'89 - '90: No consensus. No outliers.

'90 - '91: No consensus. One negative outlier supported by identification of NASA's reorganization and cutbacks in funding for CCDS's.

'91 - '92: No consensus. No outliers.

'92 - '93: No consensus. No outliers.

'93 - '94: No consensus. One negative outlier, with no confirming or denying data. Response is retained.

Factor No. 10: DoD Support

'85 - '86: No consensus. No outliers.

'86 - '87: No consensus. No outliers.

'87 - '88: No consensus. No outliers.

'88 - '89: Consensus on increase. No outliers.

'89 - '90: No consensus. No outliers.

'90 - '91: No consensus. No outliers.

'91 - '92: Consensus on increase. No outliers.

Factor No. 10: DoD Support (Cont'd.)

'92 - '93: Consensus on increase. One positive outlier supported by comment that declining DoD budgets have caused strong support of commercial space as a source of revenue.

'93 - '94: Consensus on increase, with two positive outliers. One cites the same rationale as for '92 - '93. The other is supported by comment that post-cold war climate has altered DoD's viewpoint. Both responses retained.

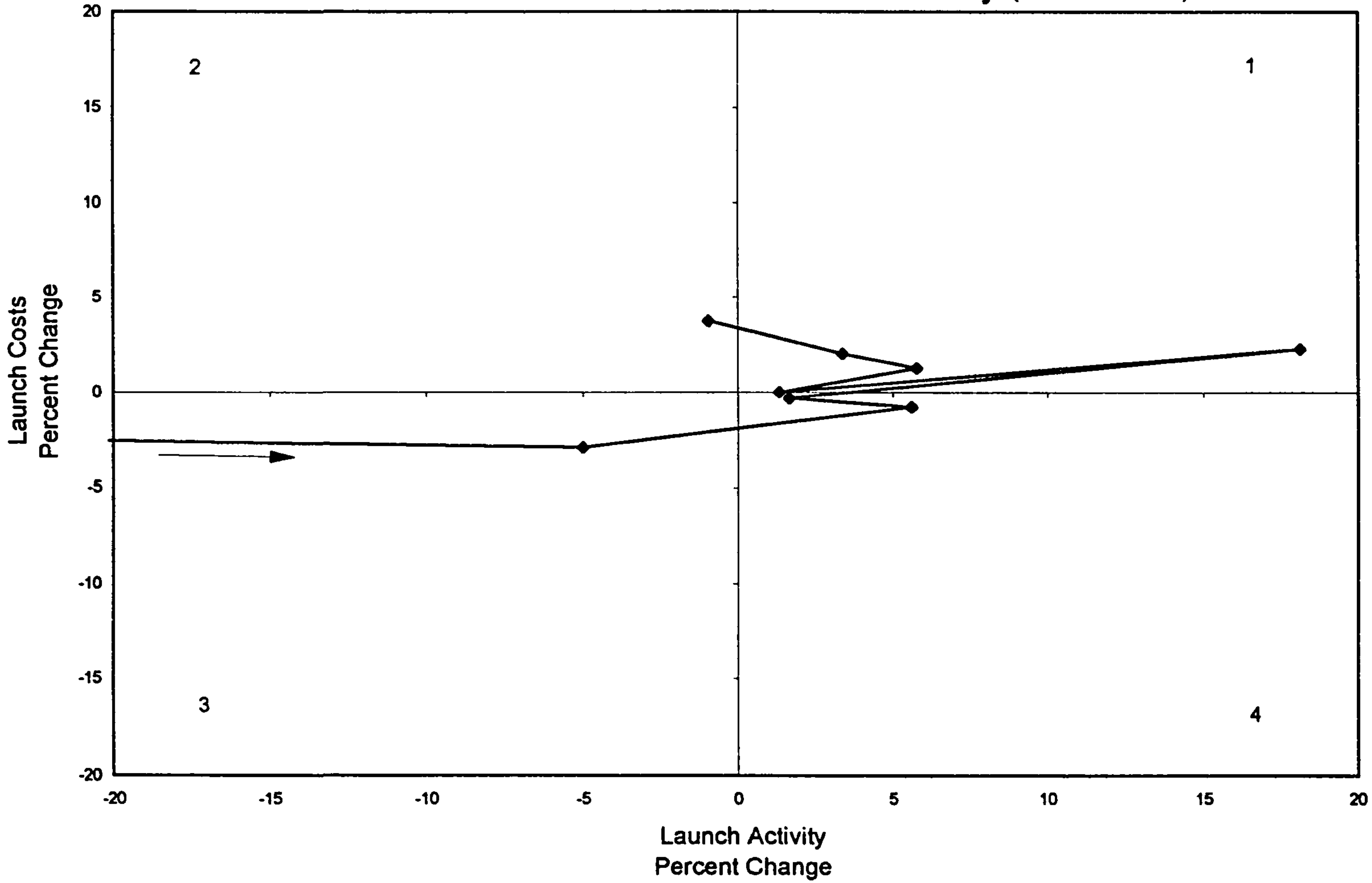
FILTERED MARGINAL CHANGE DATA

Year Pair	'85/'86	'86/87	'87/'88	'88/'89	'89/'90	'90/'91	'91/'92	'92/'93	'93/'94
Launch Costs	-1.67	-2.92	-0.78	-0.31	2.29	0	1.25	2.03	3.75
Legal/Reg. Env.	1.7	5.98	5.5	3.96	4.48	12.25	0.27	-4.64	-3.3
Fed. Admin. Support	2.41	4.8	6.5	4.64	0.31	-0.98	1.96	-1.25	-5.09
Competition	-1.76	5.88	1.88	12.19	16.57	9.27	-1.34	7.14	2.41
New Technology	3.84	9.22	11.72	19	-1.43	4.38	10.94	4.64	4.63
Public Support	-1.25	-13.96	-6.57	-6.5	-4.07	-2.5	-5.63	-1.13	-0.98
Academic Research	-19.79	-1.09	2.03	-1.25	3.13	-0.16	-1.72	-4.22	-7.71
NASA Support	-1.48	-1.17	0.15	0.78	-1.09	-5.63	-1.56	-0.08	-6.33
DoD Support	-0.27	3.04	3.21	3.3	0.63	1.07	6.72	10.36	13.96

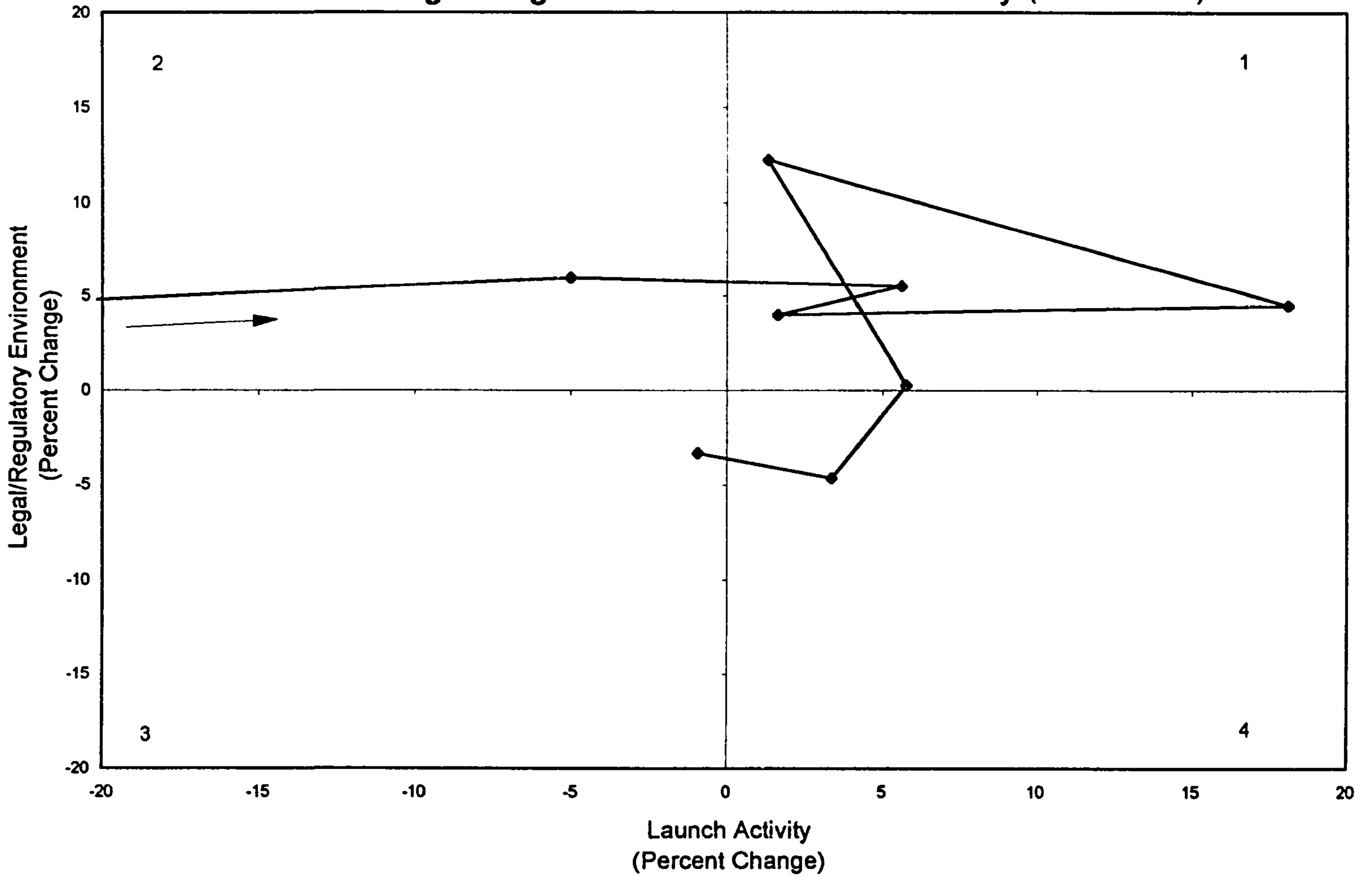
APPENDIX F

PHASE PLANE DIAGRAMS

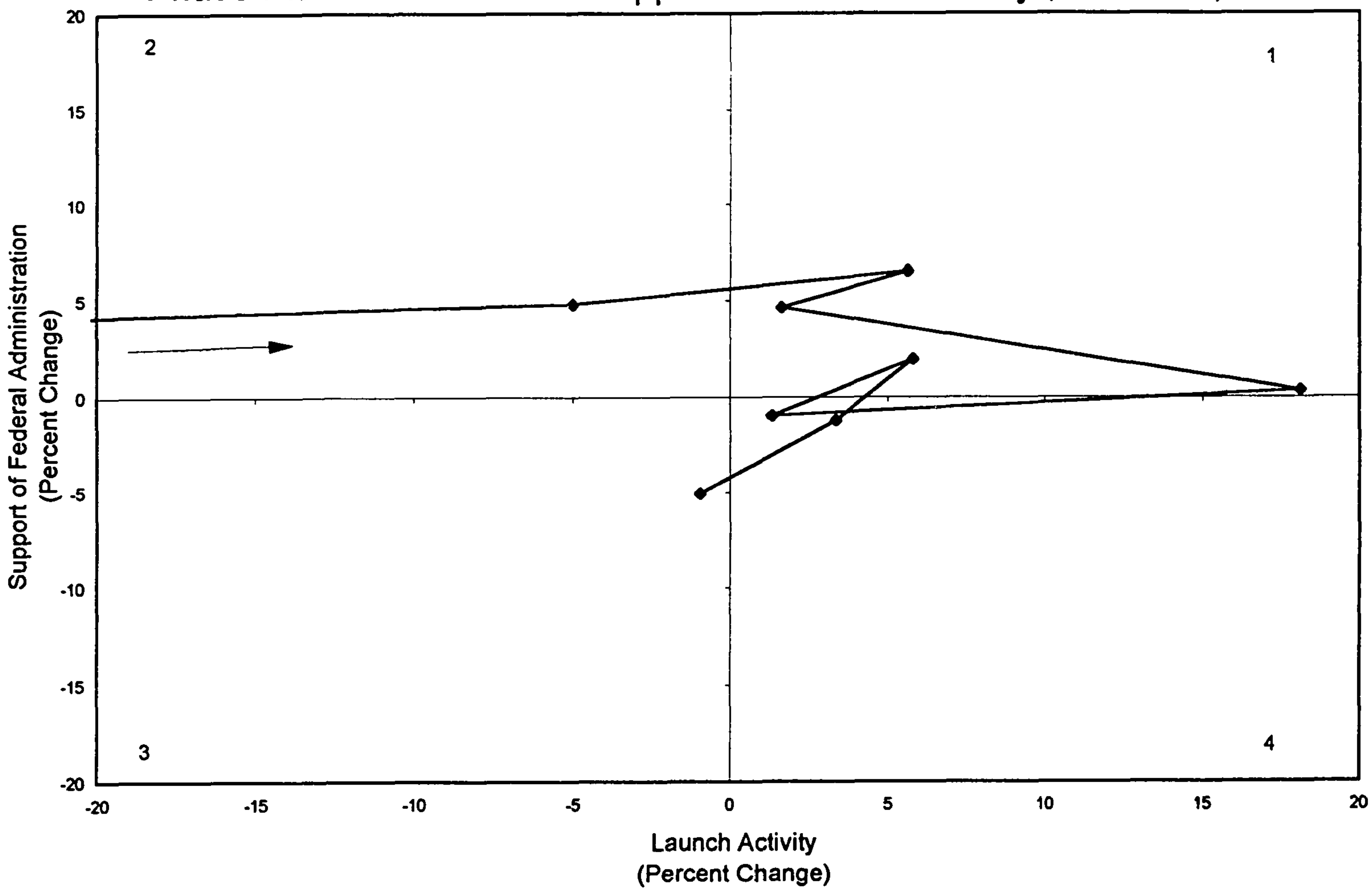
Phase Plane: Launch Cost vs. Launch Activity (Filtered Data)



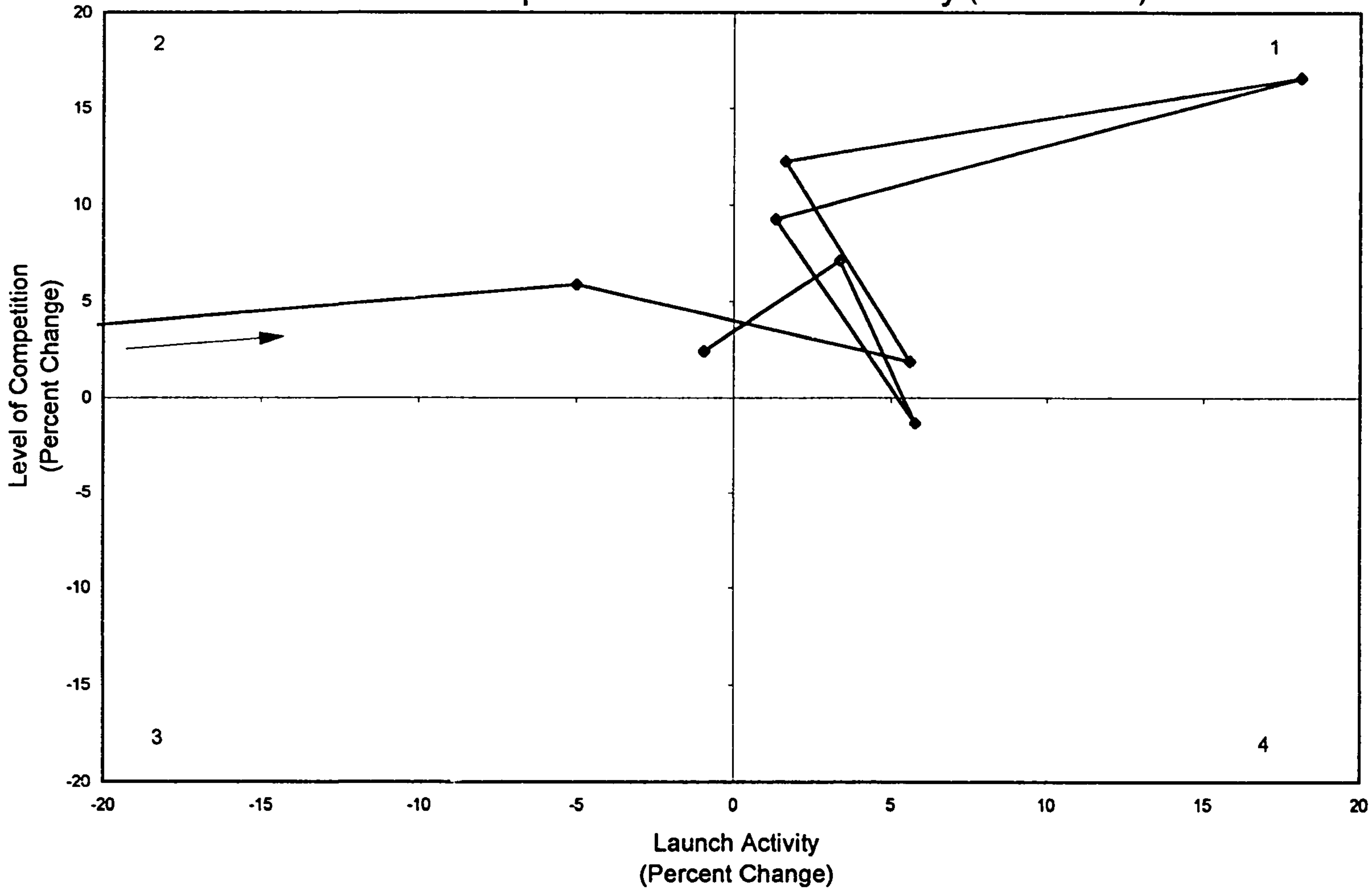
Phase Plane: Legal/Reg. Environ. vs. Launch Activity (Filtered Data)



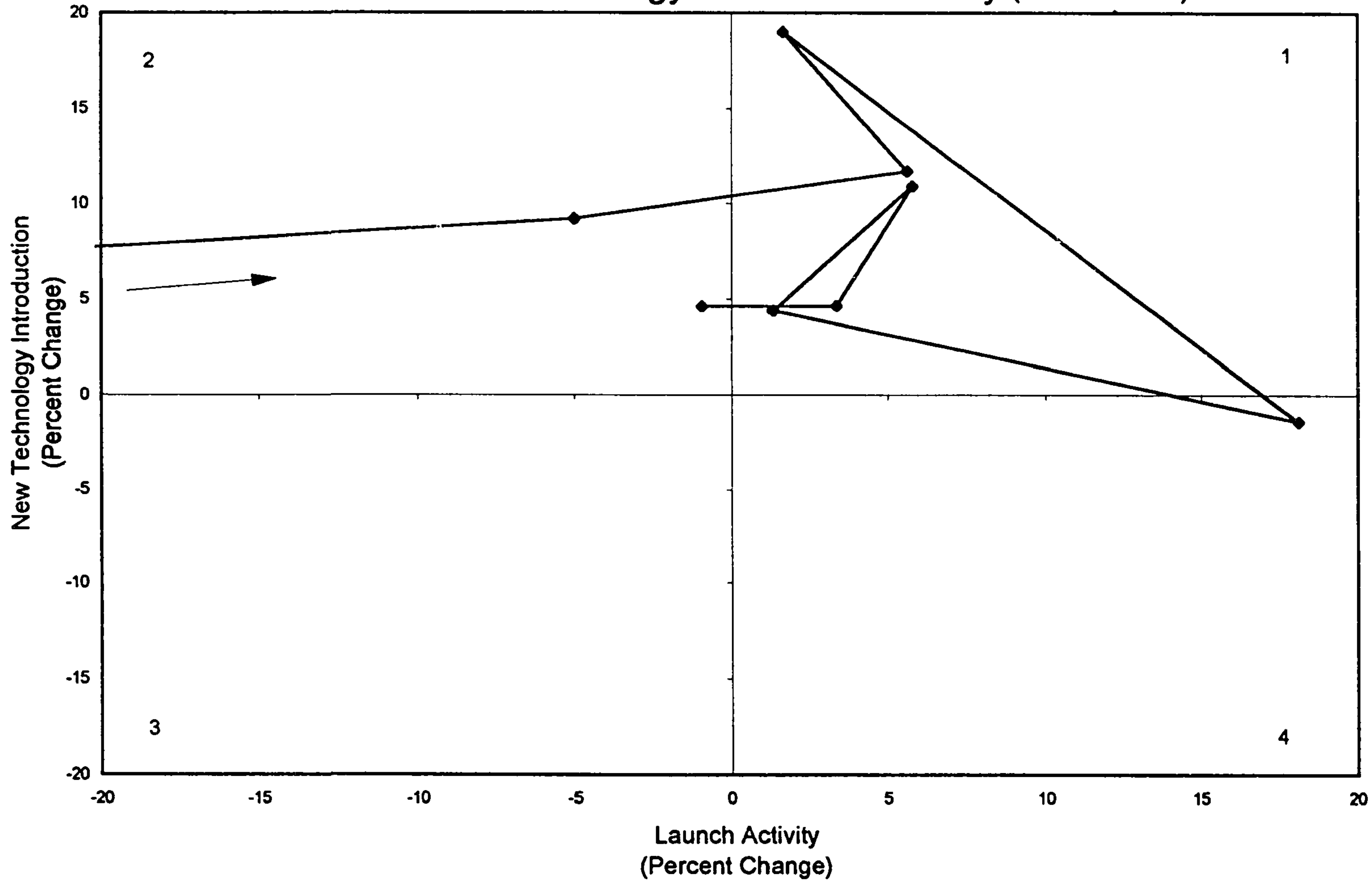
Phase Plane: Fed. Admin. Support vs. Launch Activity (Filtered Data)



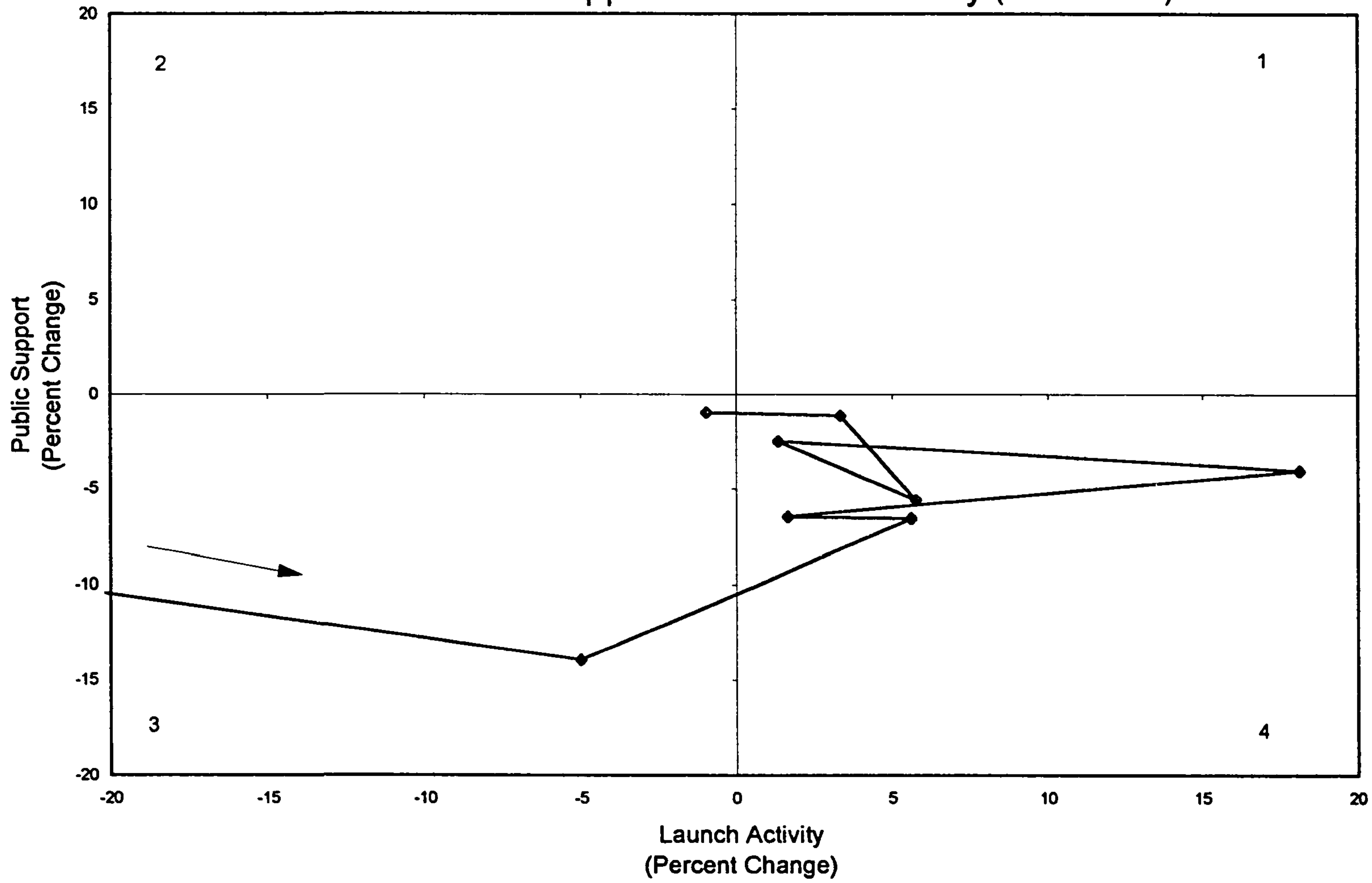
Phase Plane: Competition vs. Launch Activity (Filtered Data)



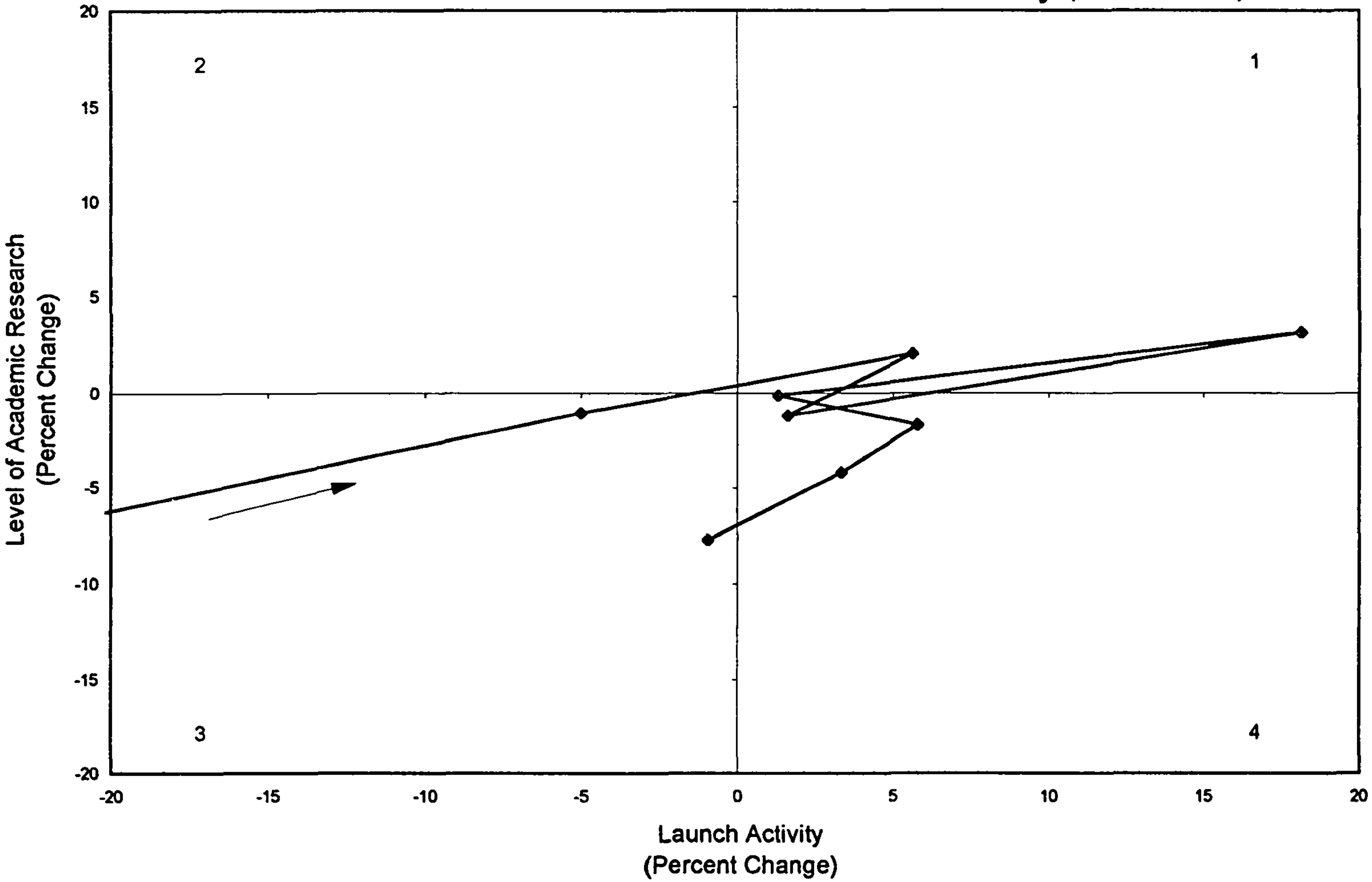
Phase Plane: New Technology vs. Launch Activity (Filtered Data)



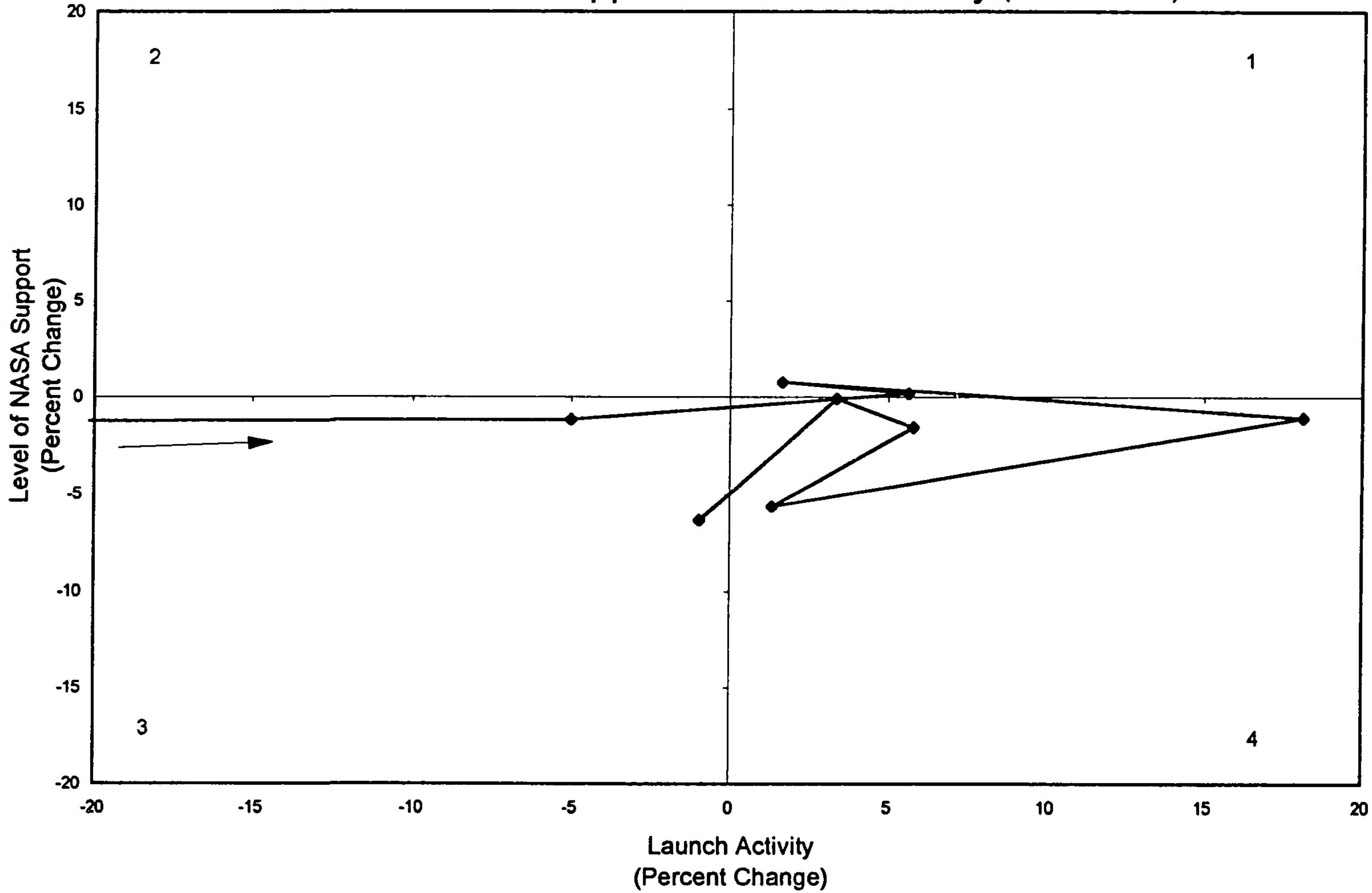
Phase Plane: Public Support vs. Launch Activity (Filtered Data)



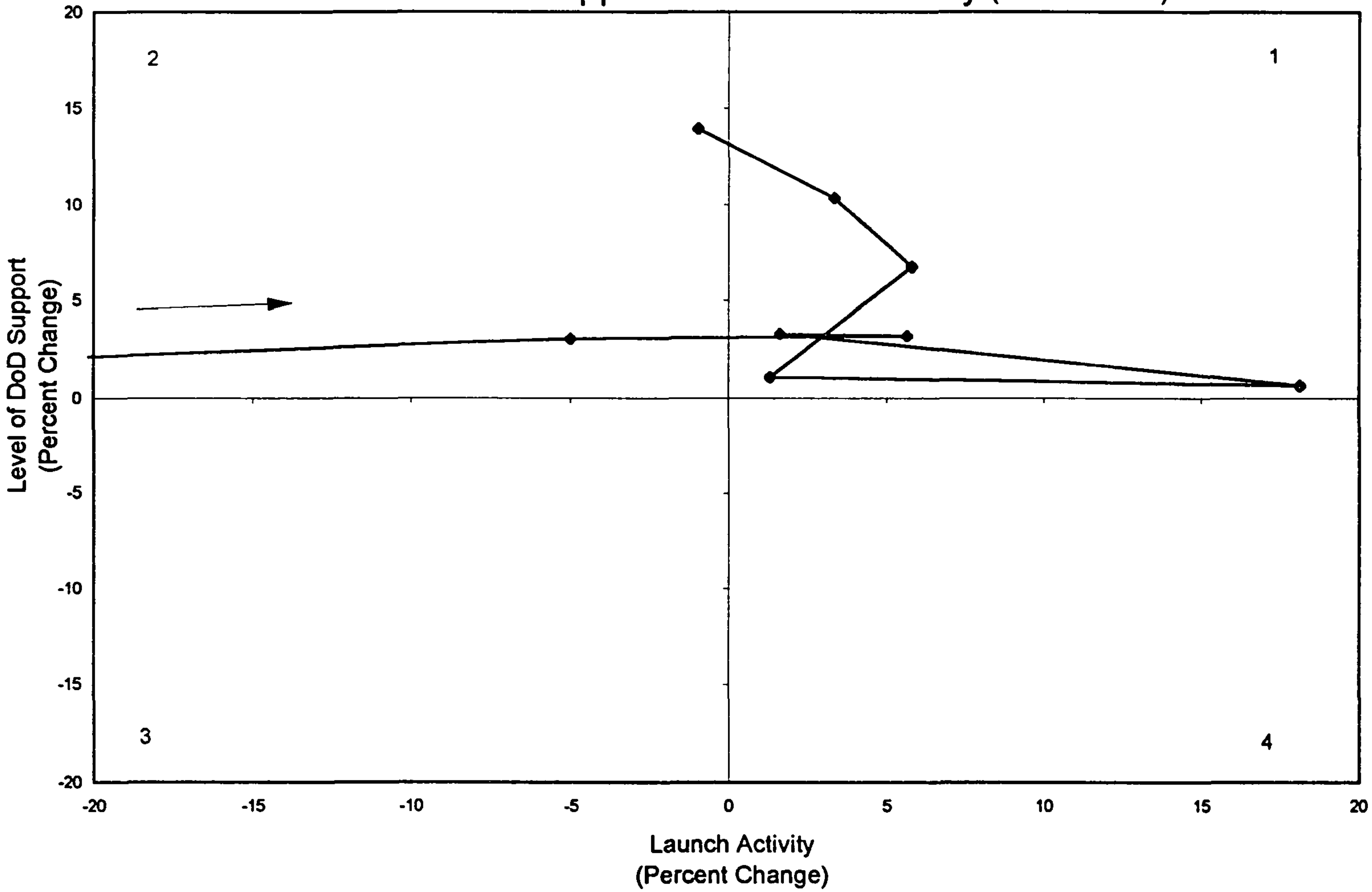
Phase Plane: Academic Research vs. Launch Activity (Filtered Data)



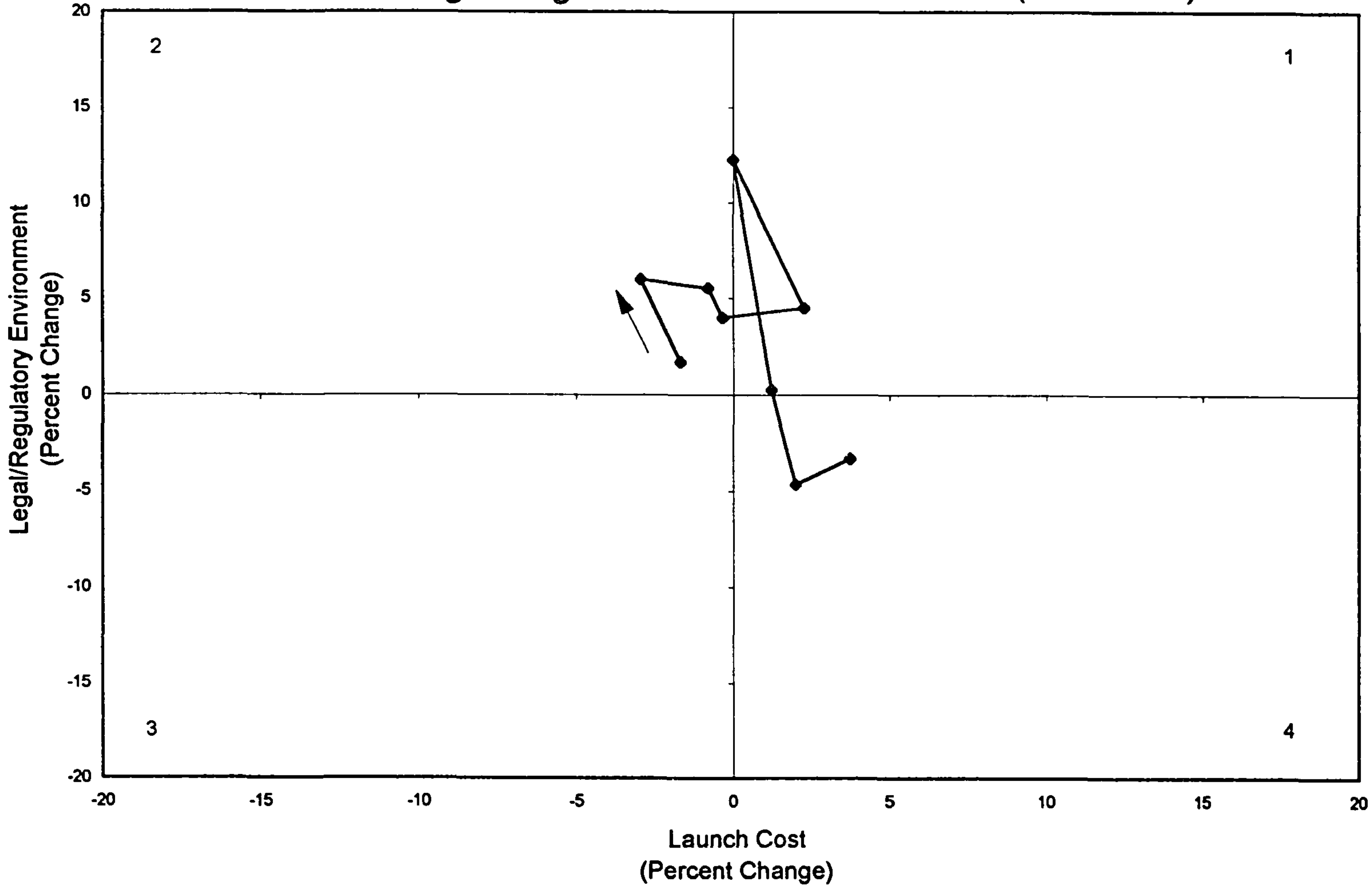
Phase Plane: NASA Support vs. Launch Activity (Filtered Data)

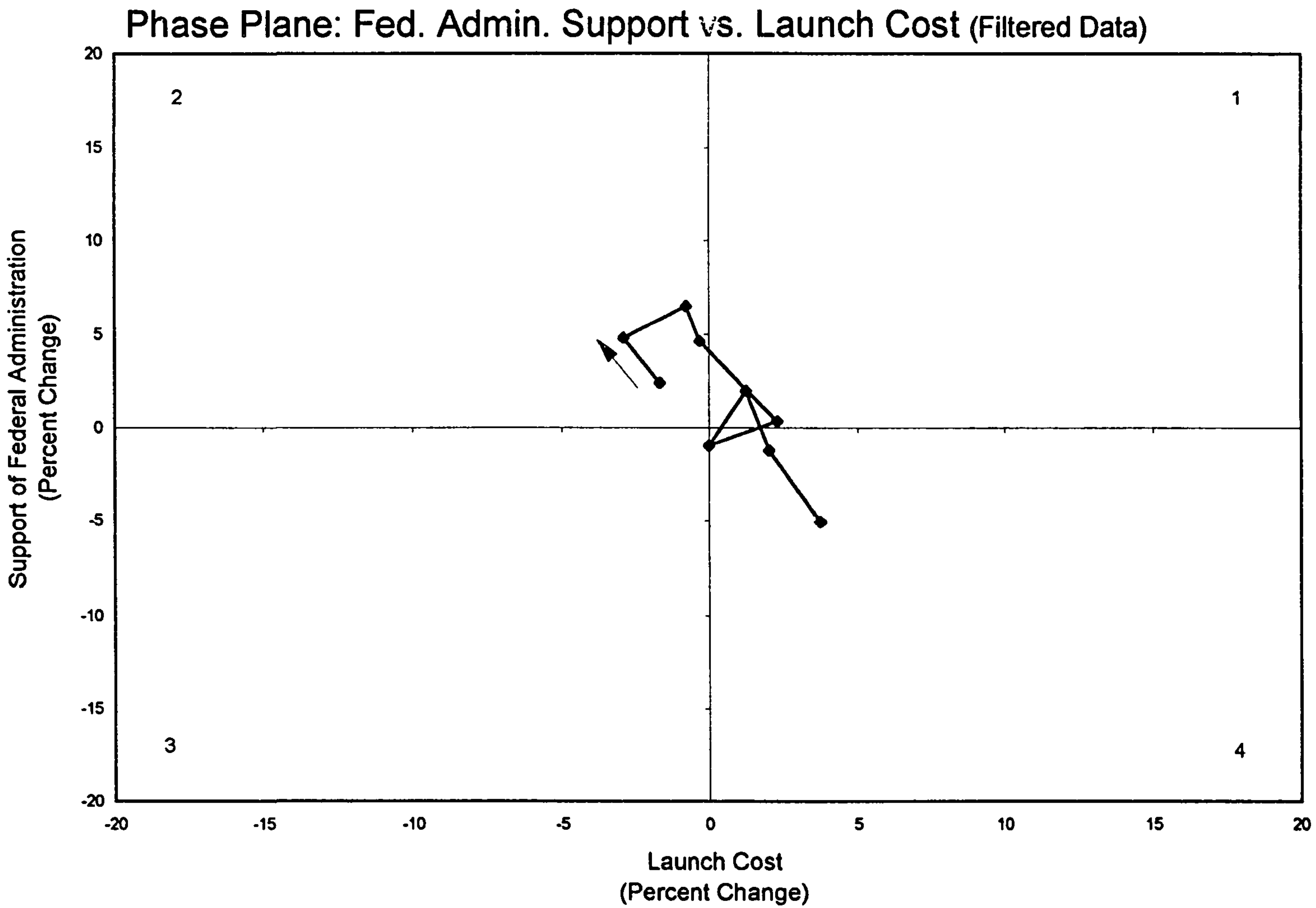


Phase Plane: DoD Support vs. Launch Activity (Filtered Data)

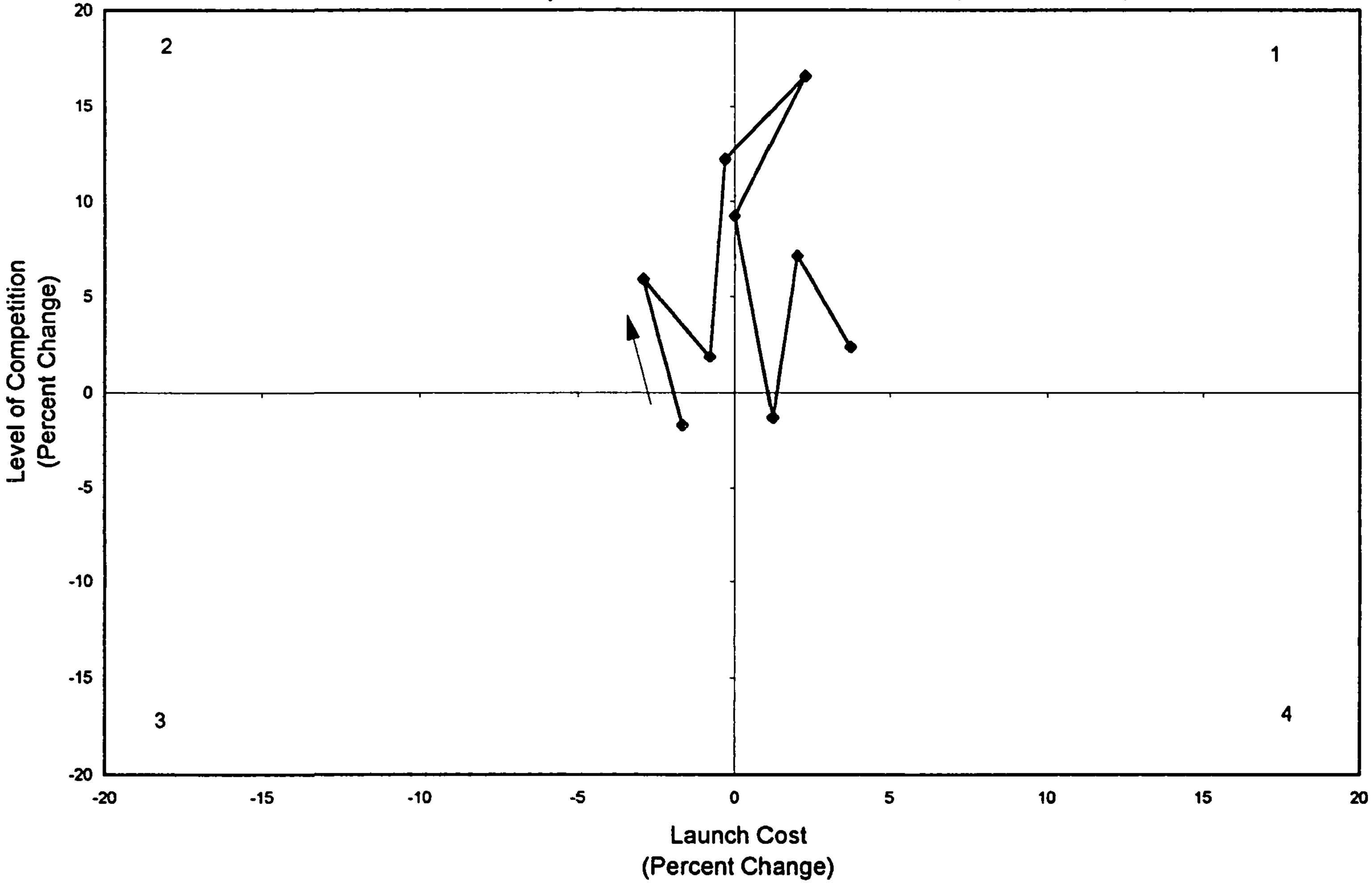


Phase Plane: Legal/Reg. Environ. vs. Launch Cost (Filtered Data)

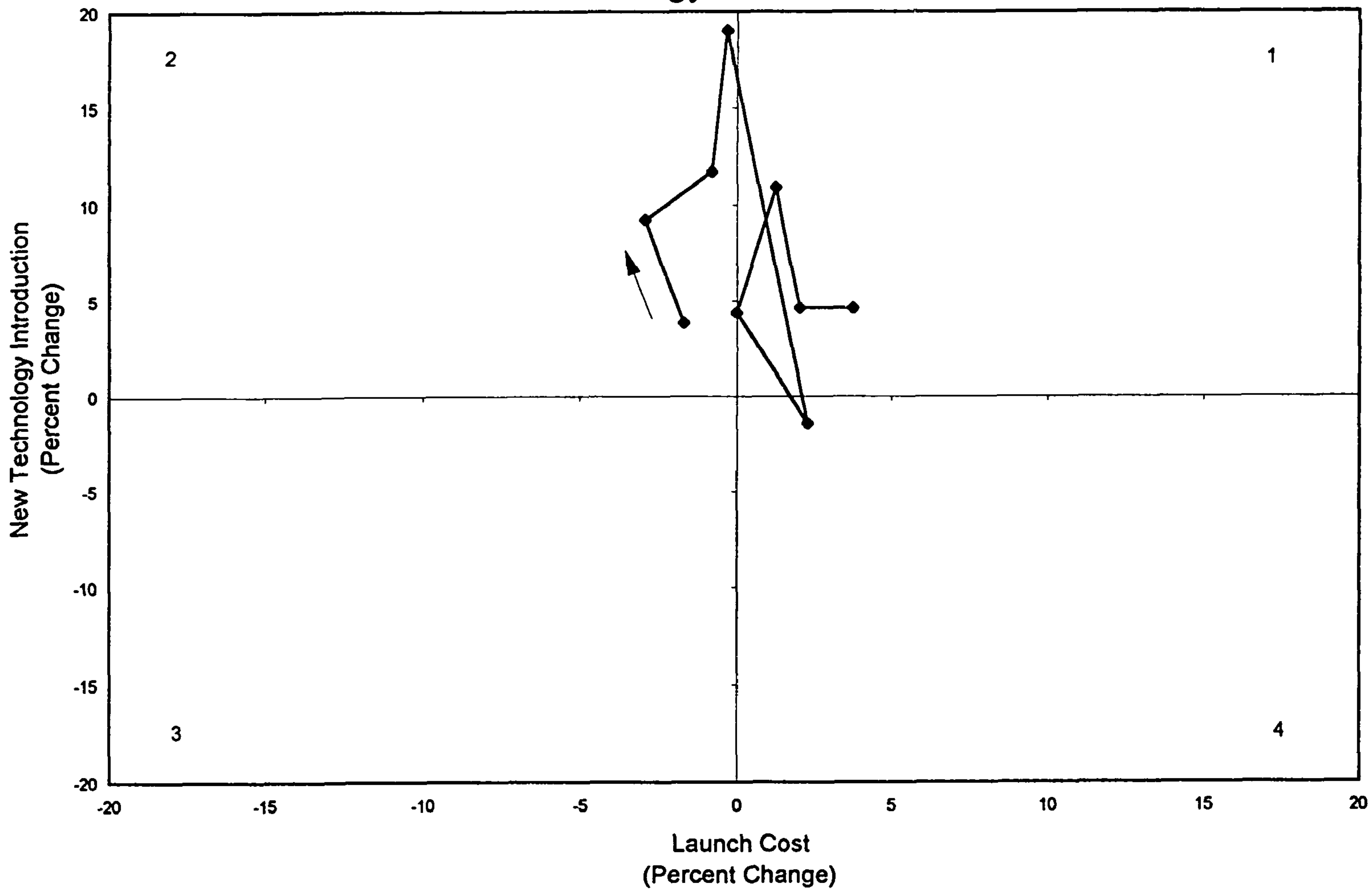



Phase Plane: Fed. Admin. Support vs. Launch Cost (Filtered Data)
Support of Federal Administration (Percent Change)
Launch Cost (Percent Change)
1
2
3
4
20
15
10
5
0
-5
-10
-15
-20
-20
-15
-10
-5
0
5
10
15
20

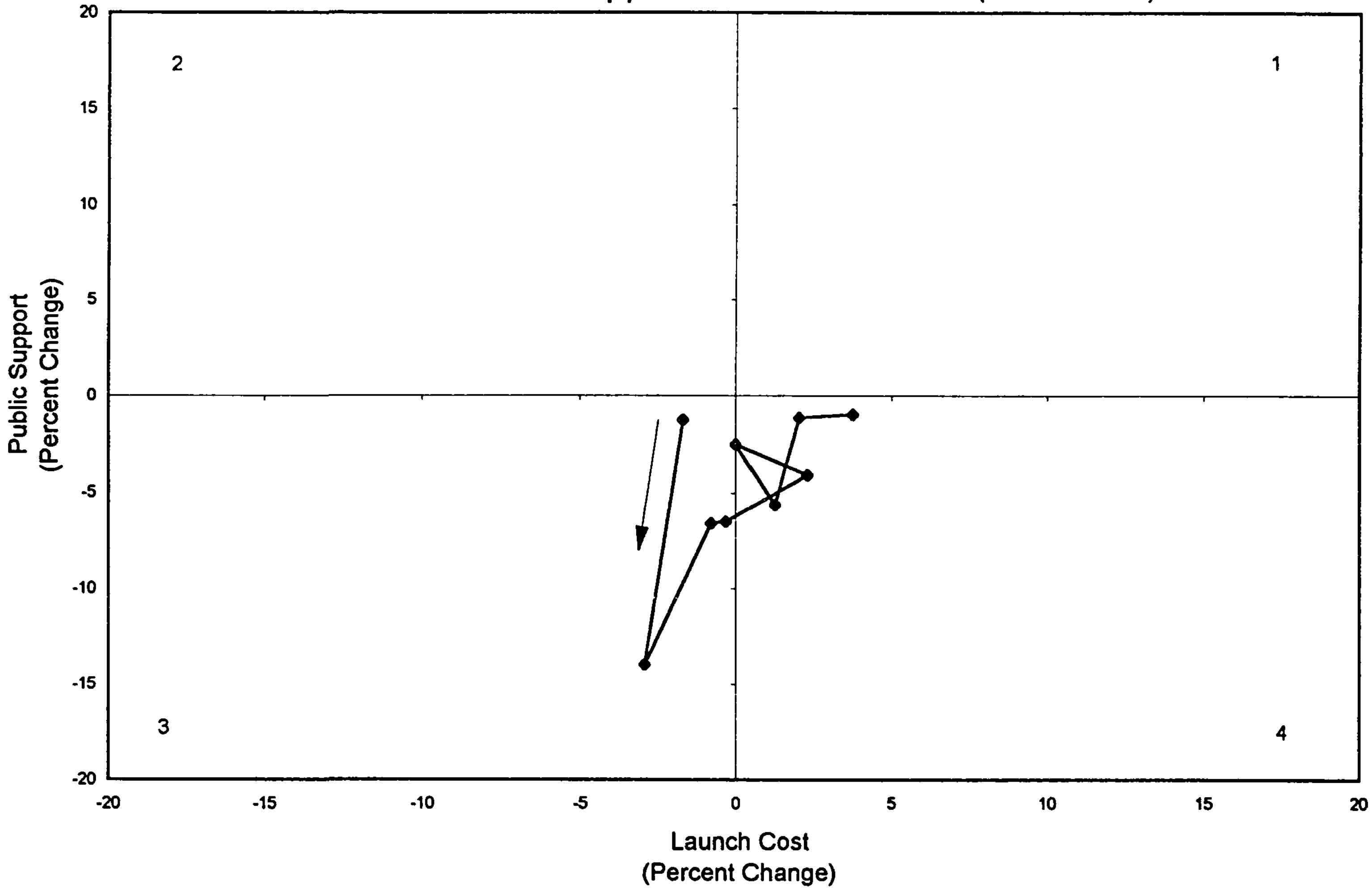
Phase Plane: Competition vs. Launch Cost (Filtered Data)



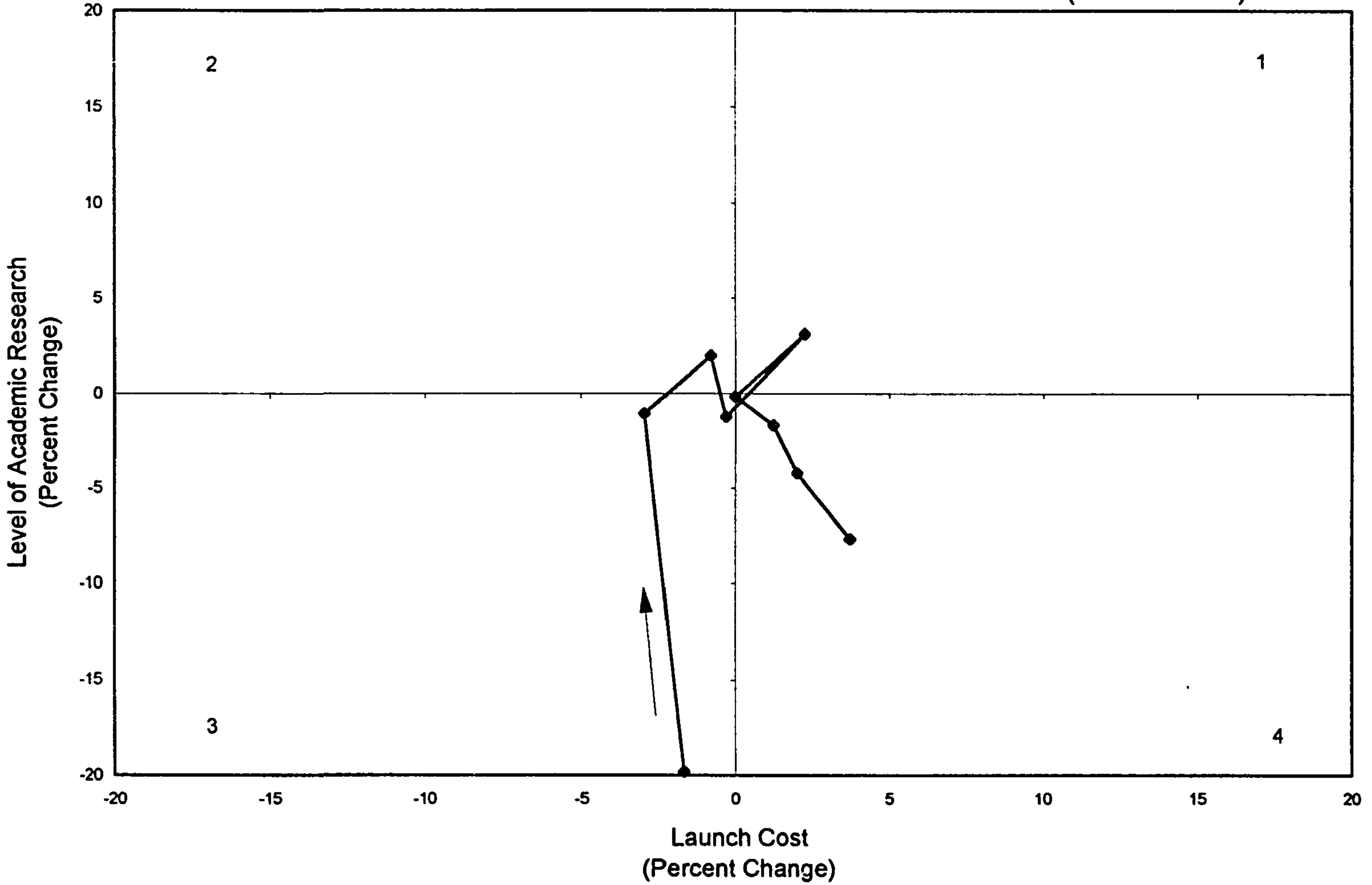
Phase Plane: New Technology vs. Launch Cost (Filtered Data)



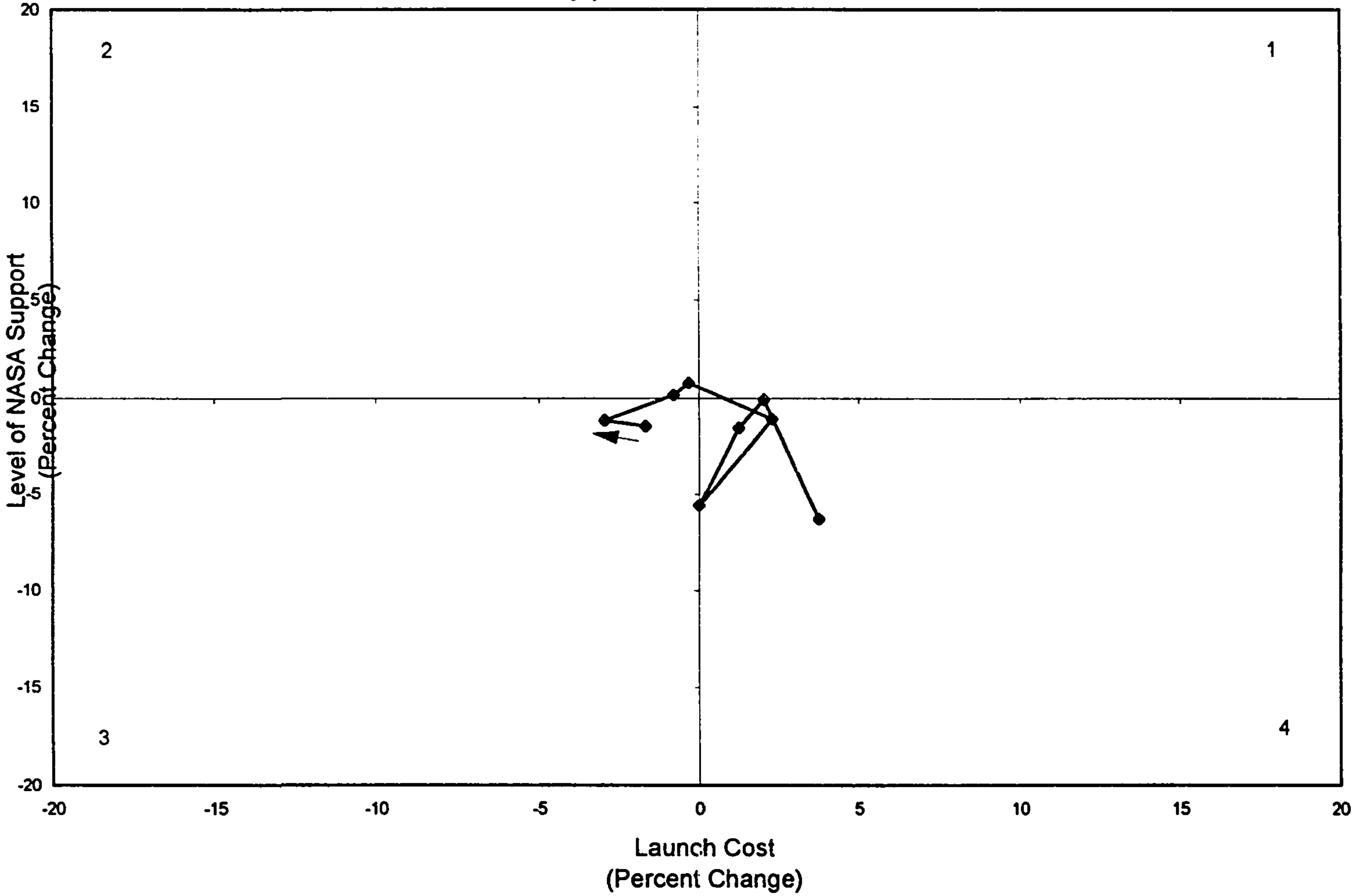
Phase Plane: Public Support vs. Launch Cost (Filtered Data)



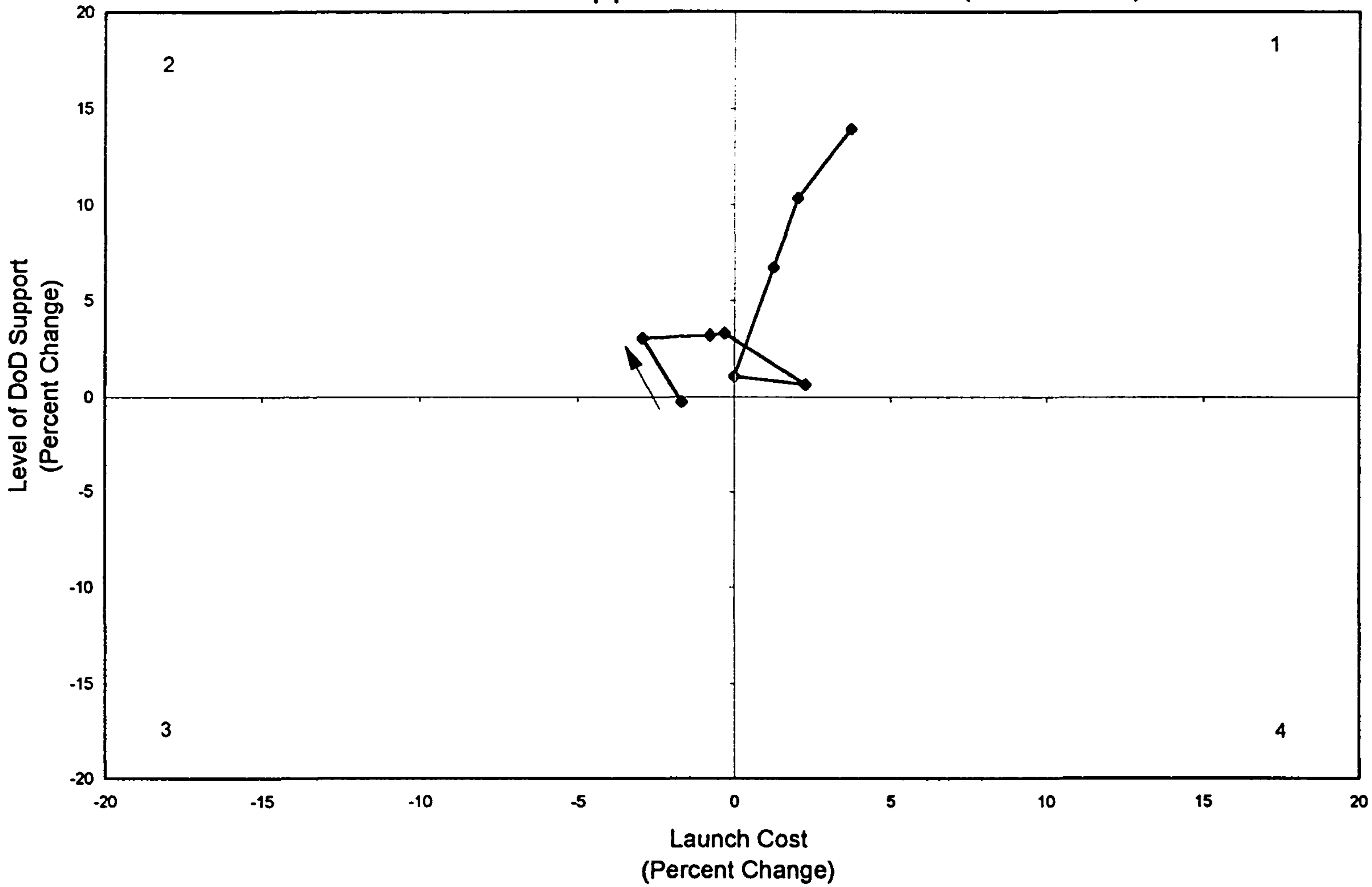
Phase Plane: Academic Research vs. Launch Cost (Filtered Data)



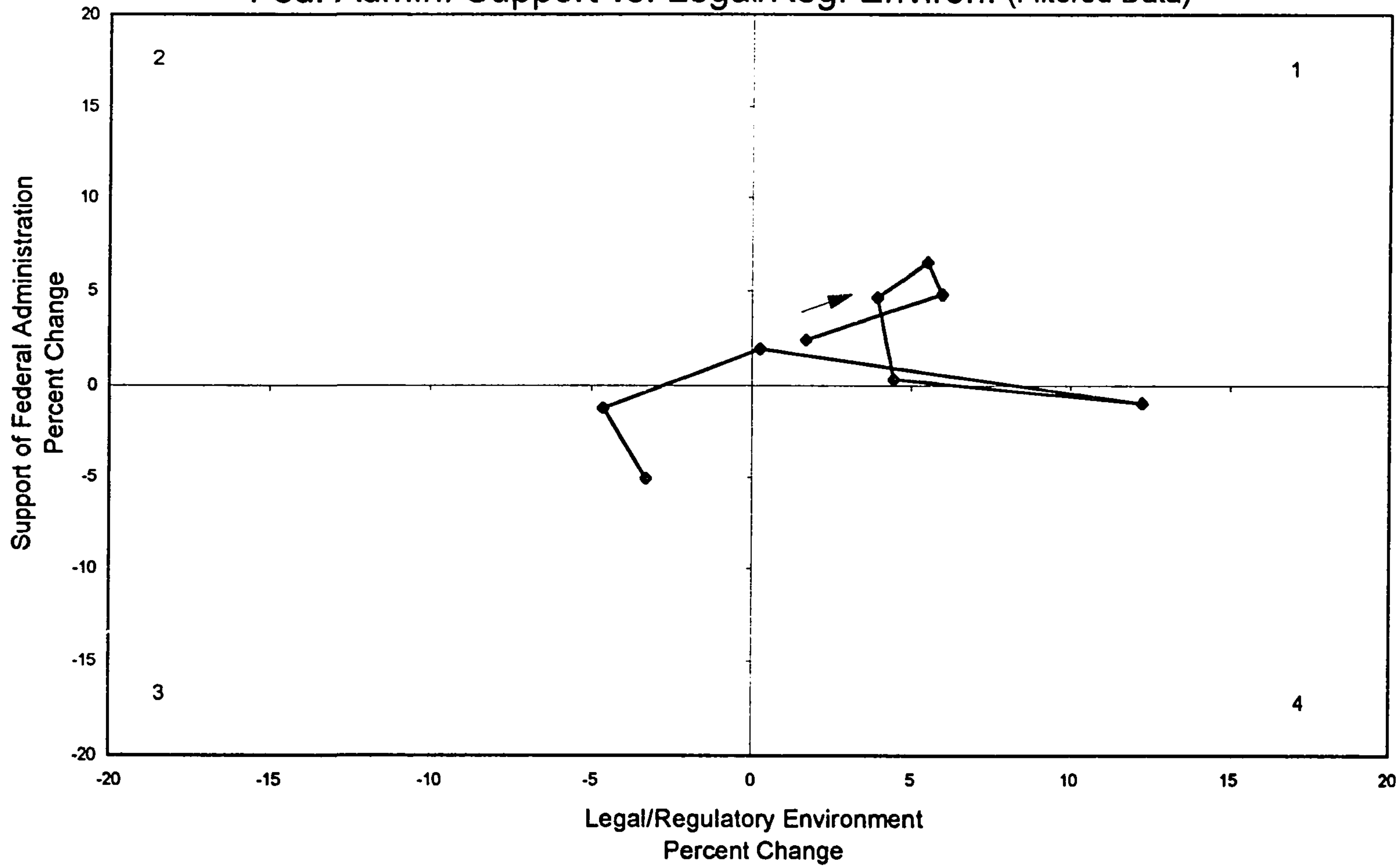
Phase Plane: NASA Support vs. Launch Cost (Filtered Data)



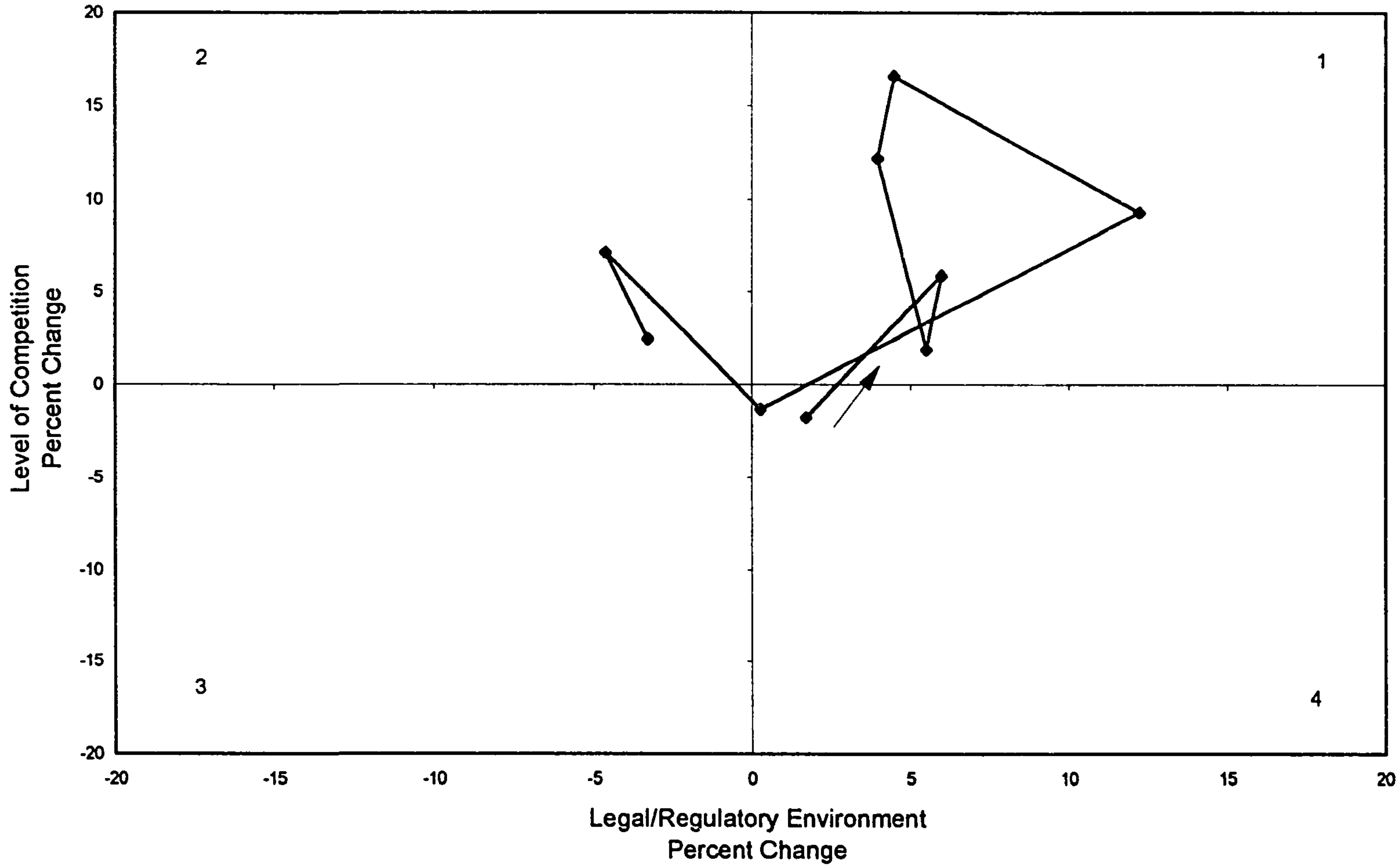
Phase Plane: DoD Support vs. Launch Cost (Filtered Data)



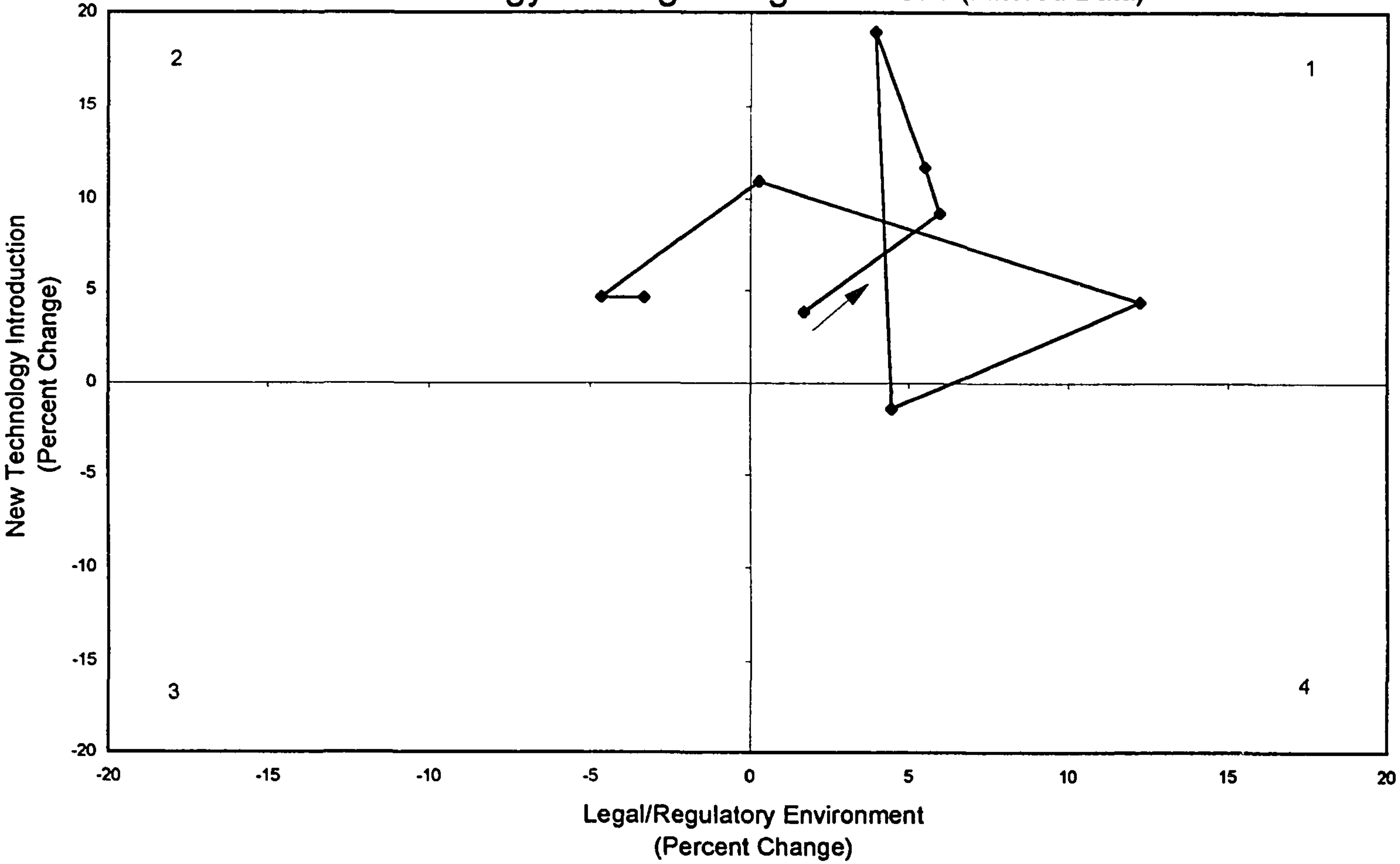
Phase Plane:
Fed. Admin. Support vs. Legal/Reg. Environ. (Filtered Data)



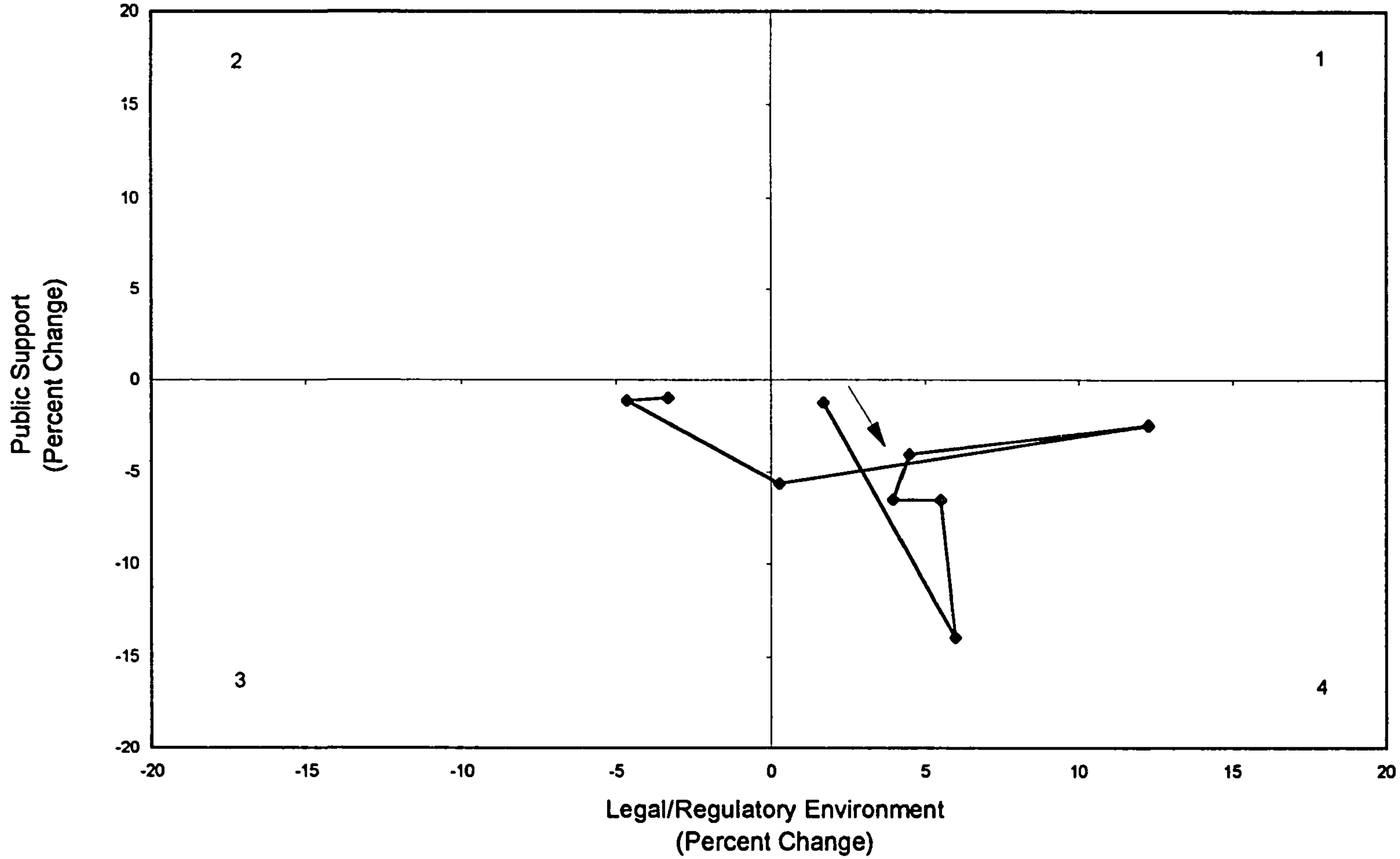
Phase Plane: Competition vs. Legal/Reg. Environ. (Filtered Data)



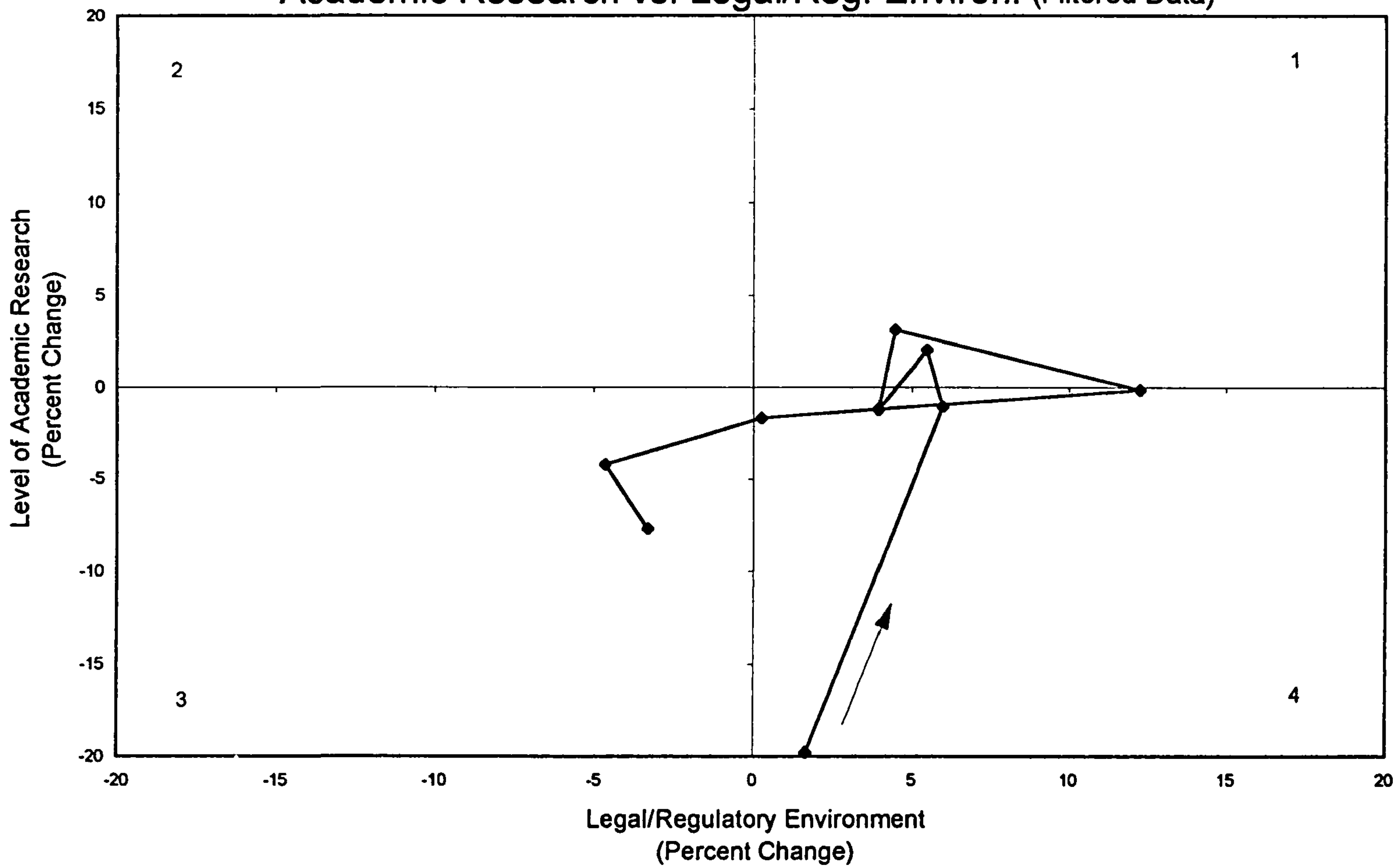
Phase Plane:
New Technology vs. Legal/Reg. Environ. (Filtered Data)



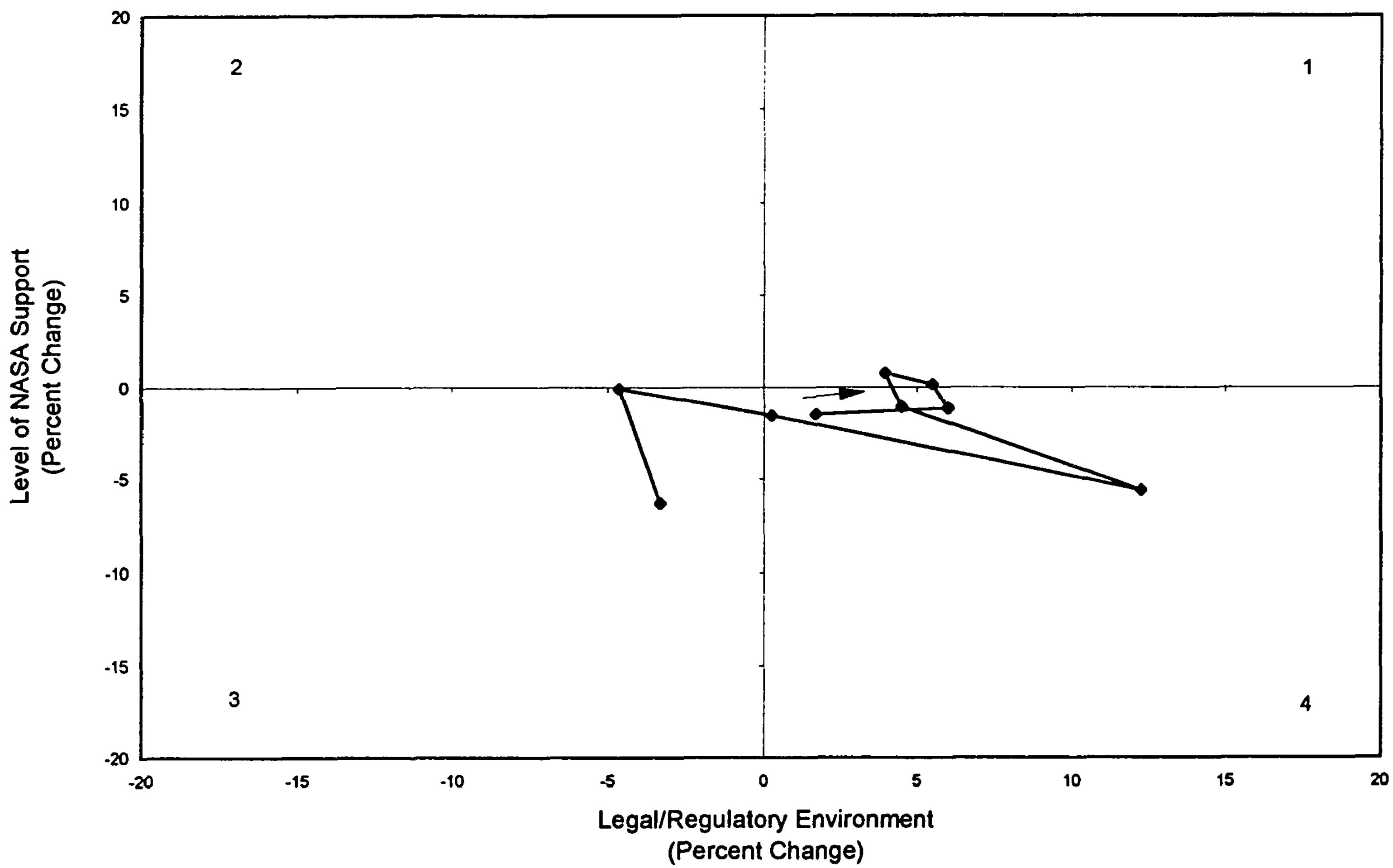
Phase Plane: Public Support vs. Legal/Reg. Environ. (Filtered Data)



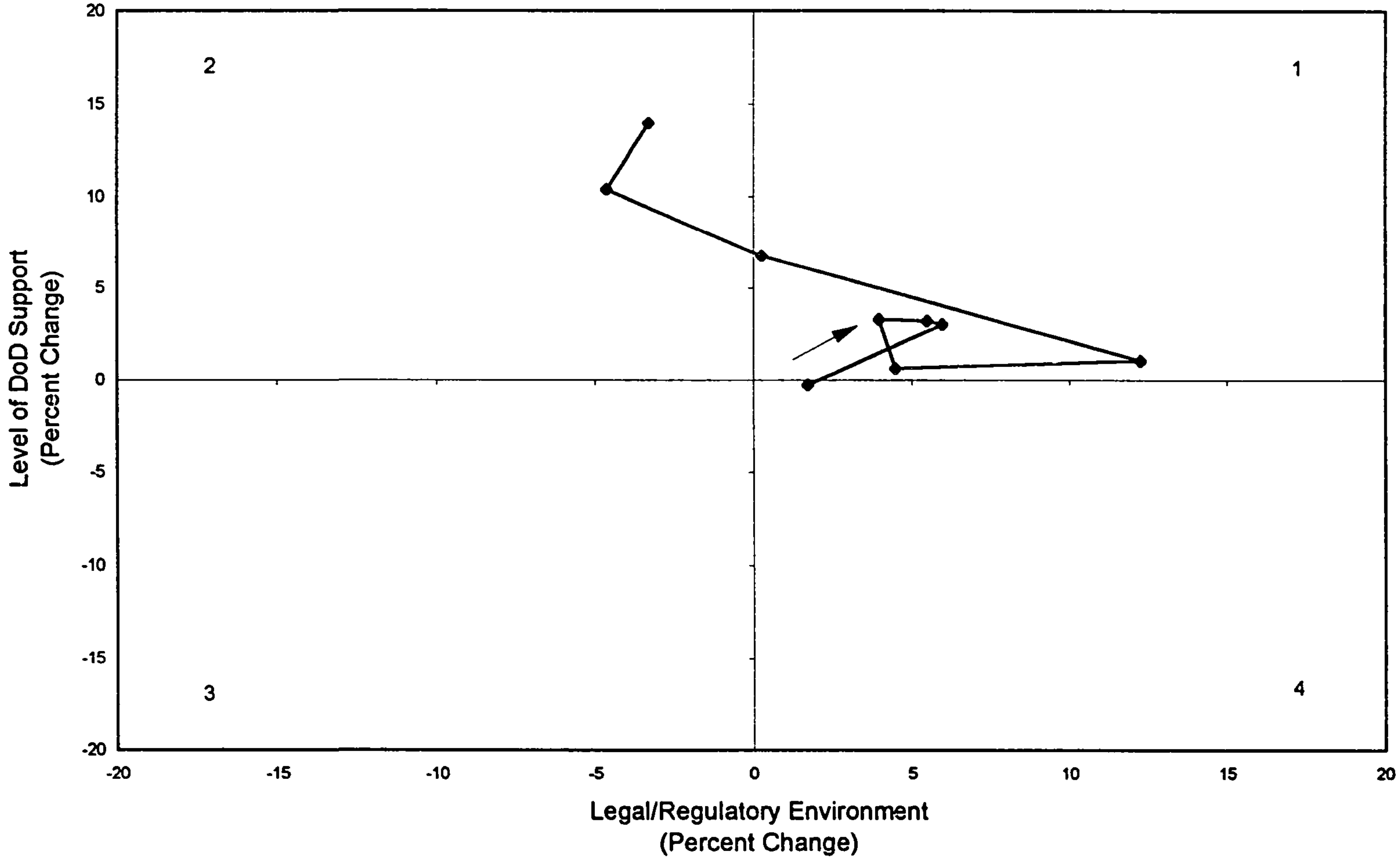
Phase Plane:
Academic Research vs. Legal/Reg. Environ. (Filtered Data)



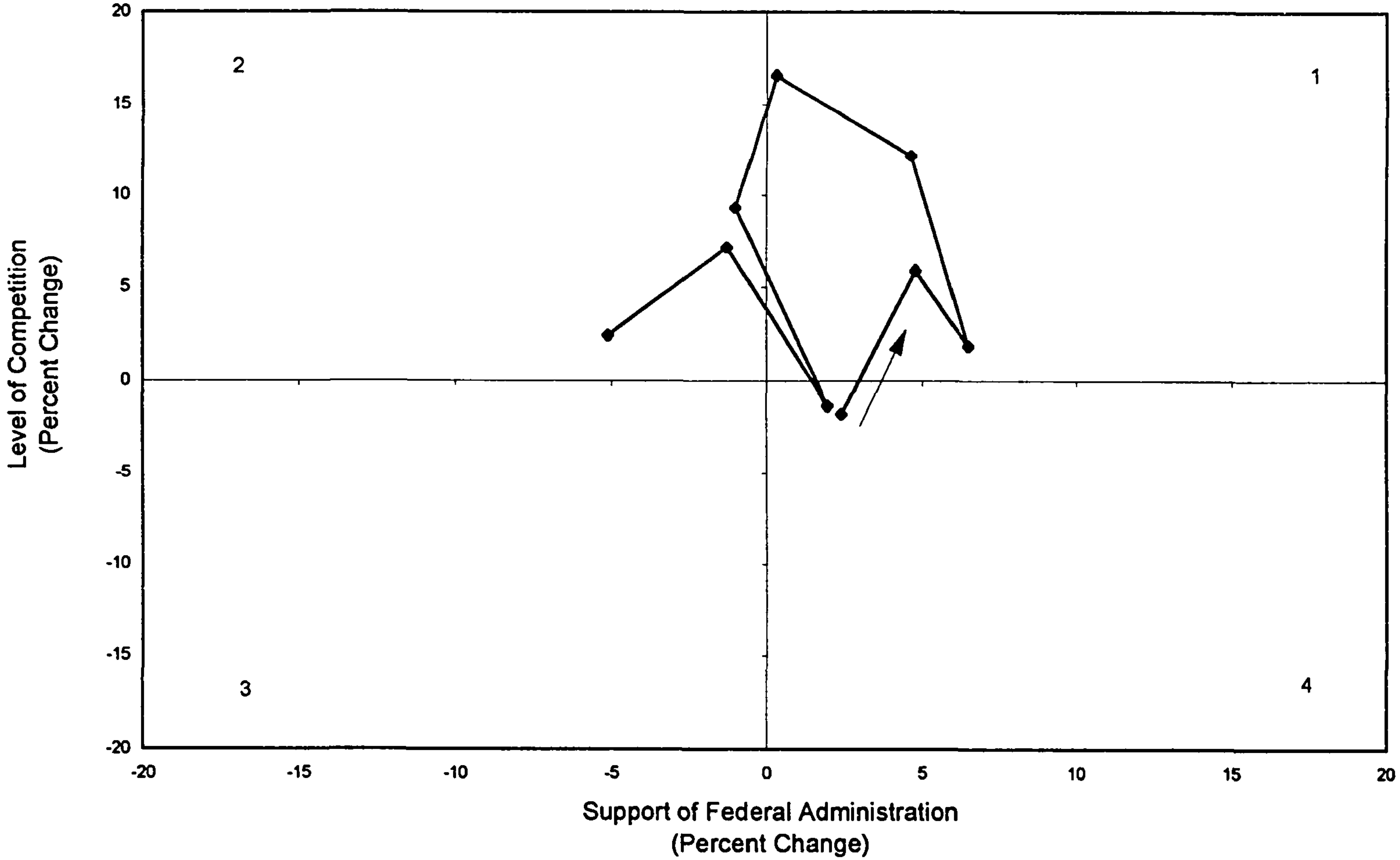
Phase Plane: NASA Support vs. Legal/Reg. Environ. (Filtered Data)



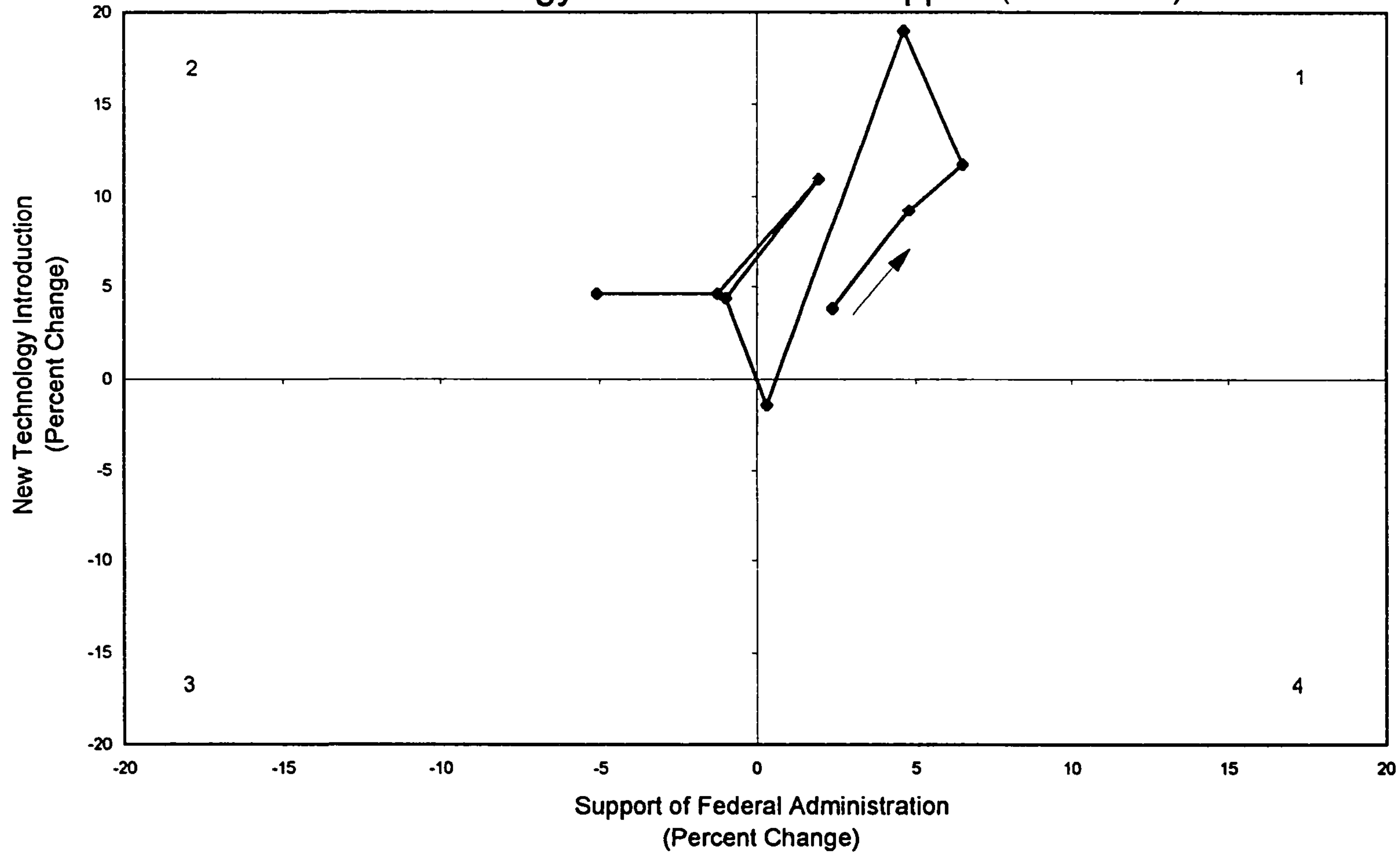
Phase Plane: DoD Support vs. Legal/Reg. Environ. (Filtered Data)



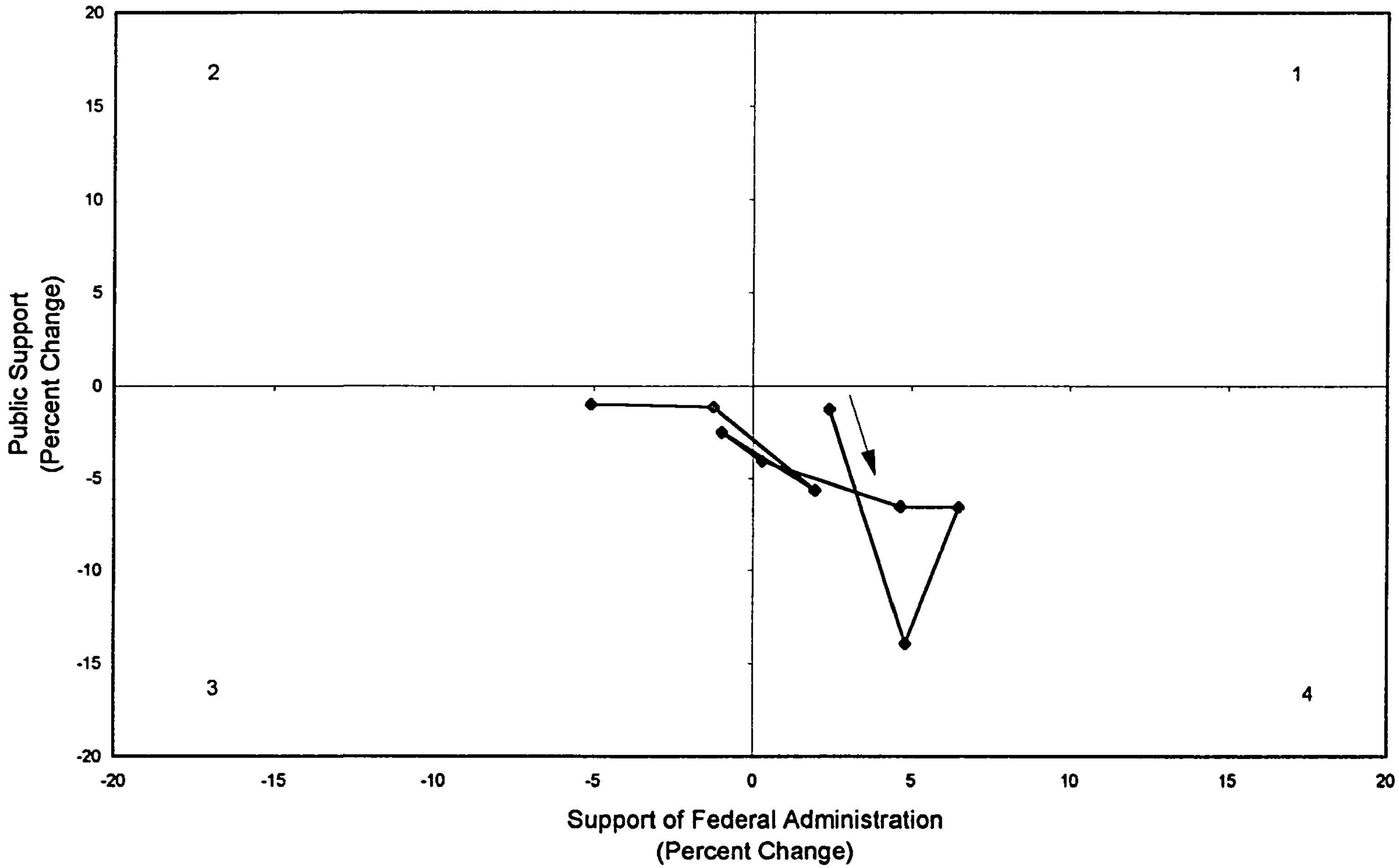
Phase Plane: Competition vs. Fed. Admin. Support (Filtered Data)



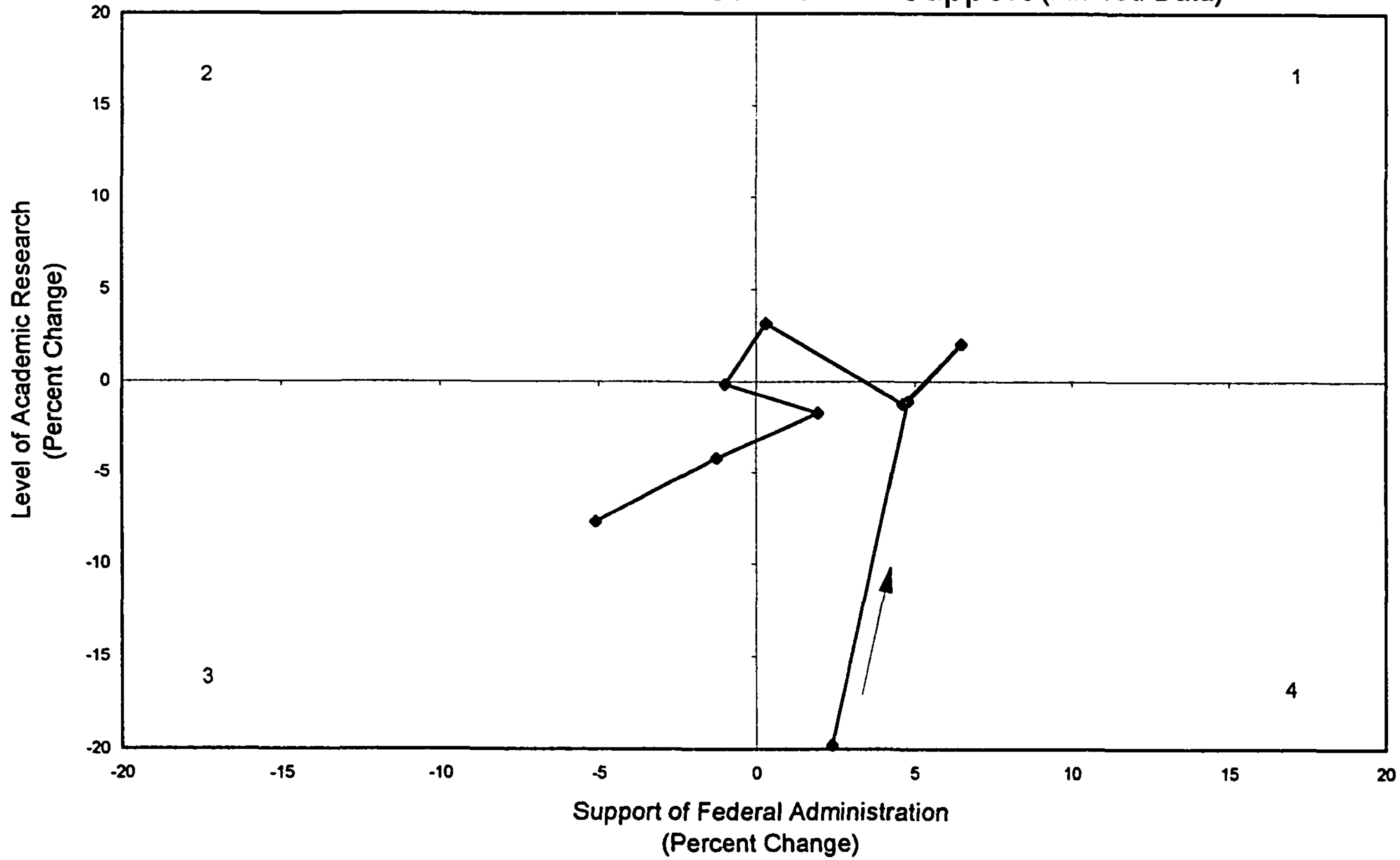
Phase Plane:
New Technology vs. Fed. Admin. Support (Filtered Data)



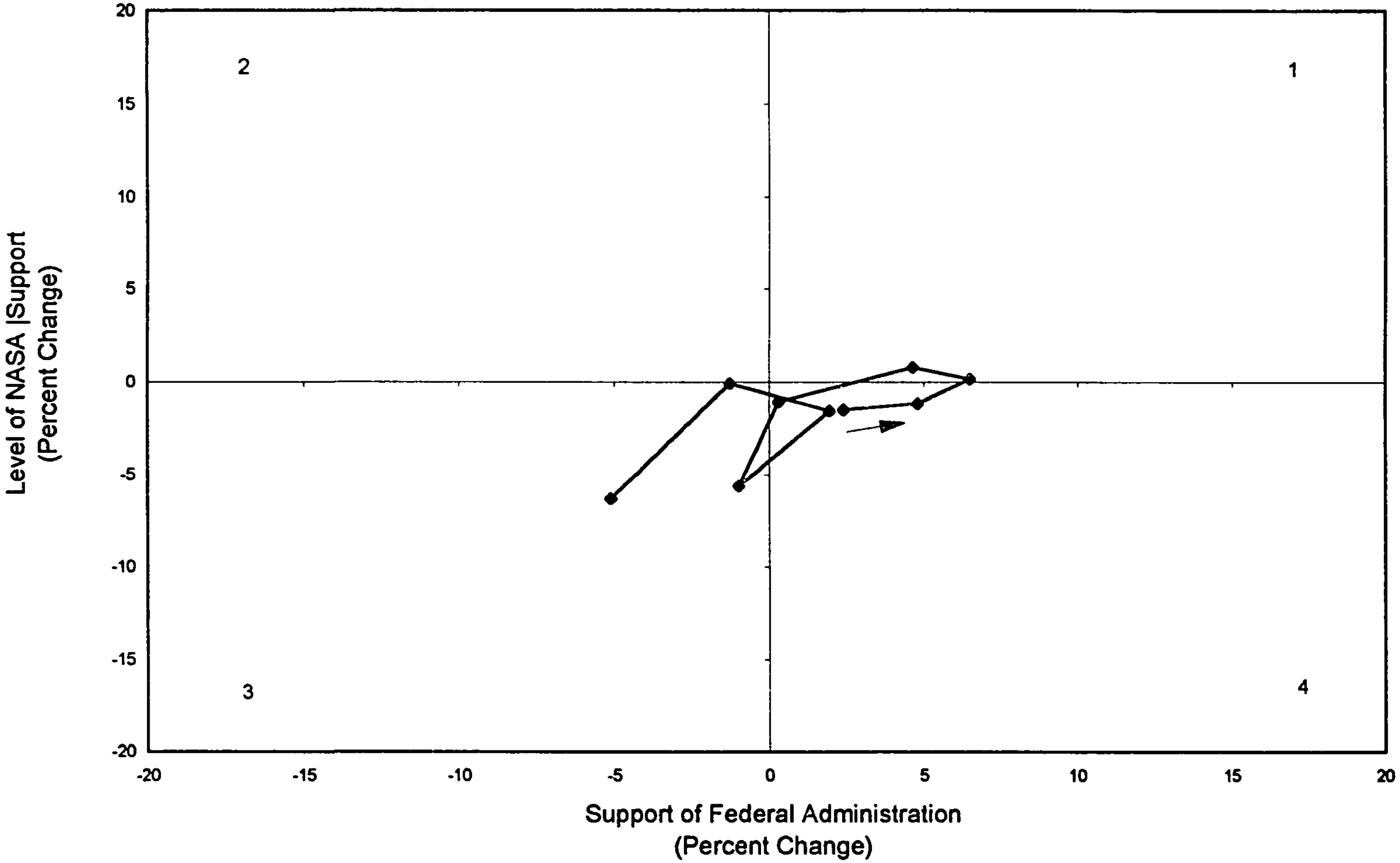
Phase Plane: Public Support vs. Fed. Admin. Support (Filtered Data)



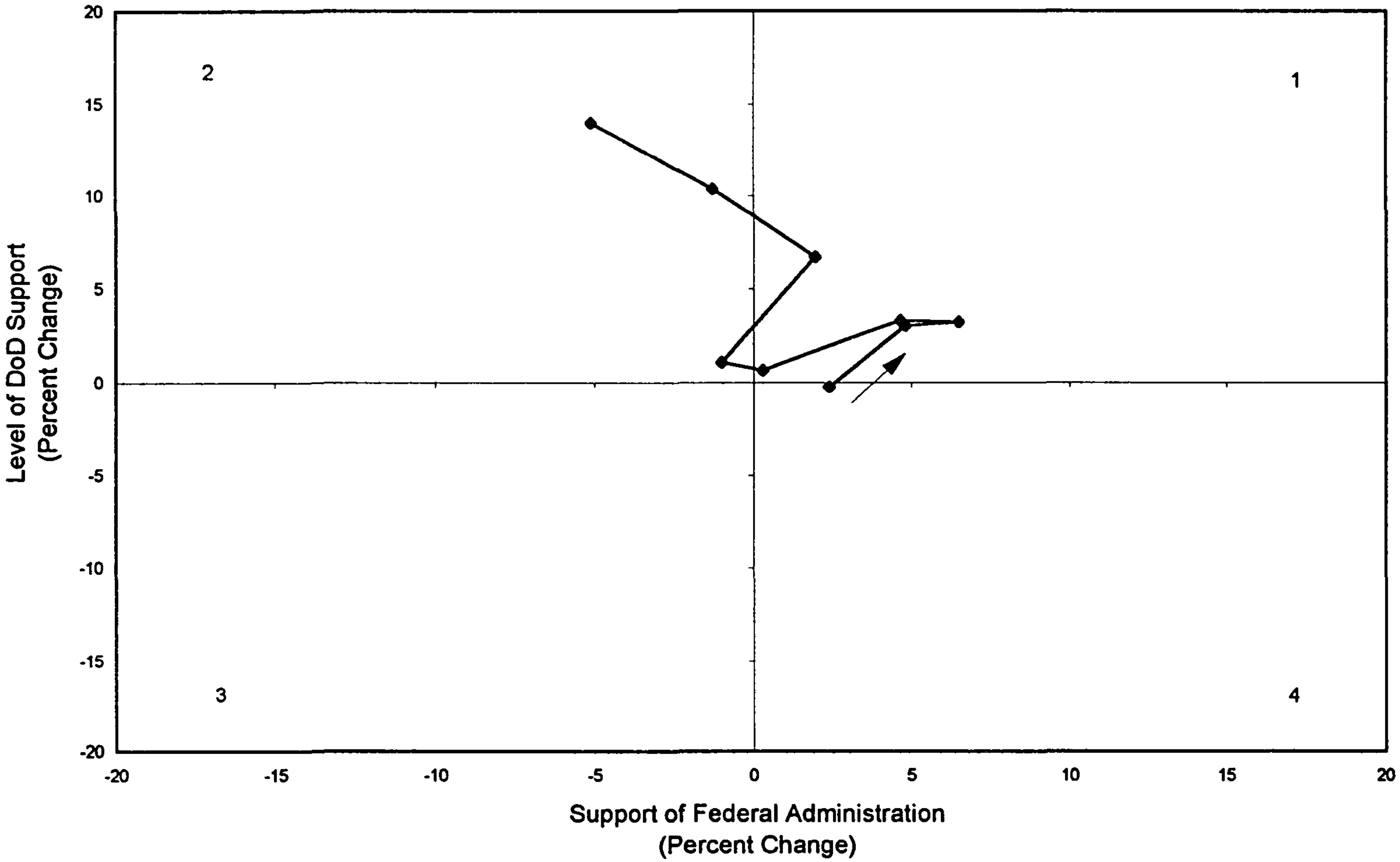
Phase Plane:
Academic Research vs. Fed. Admin. Support (Filtered Data)



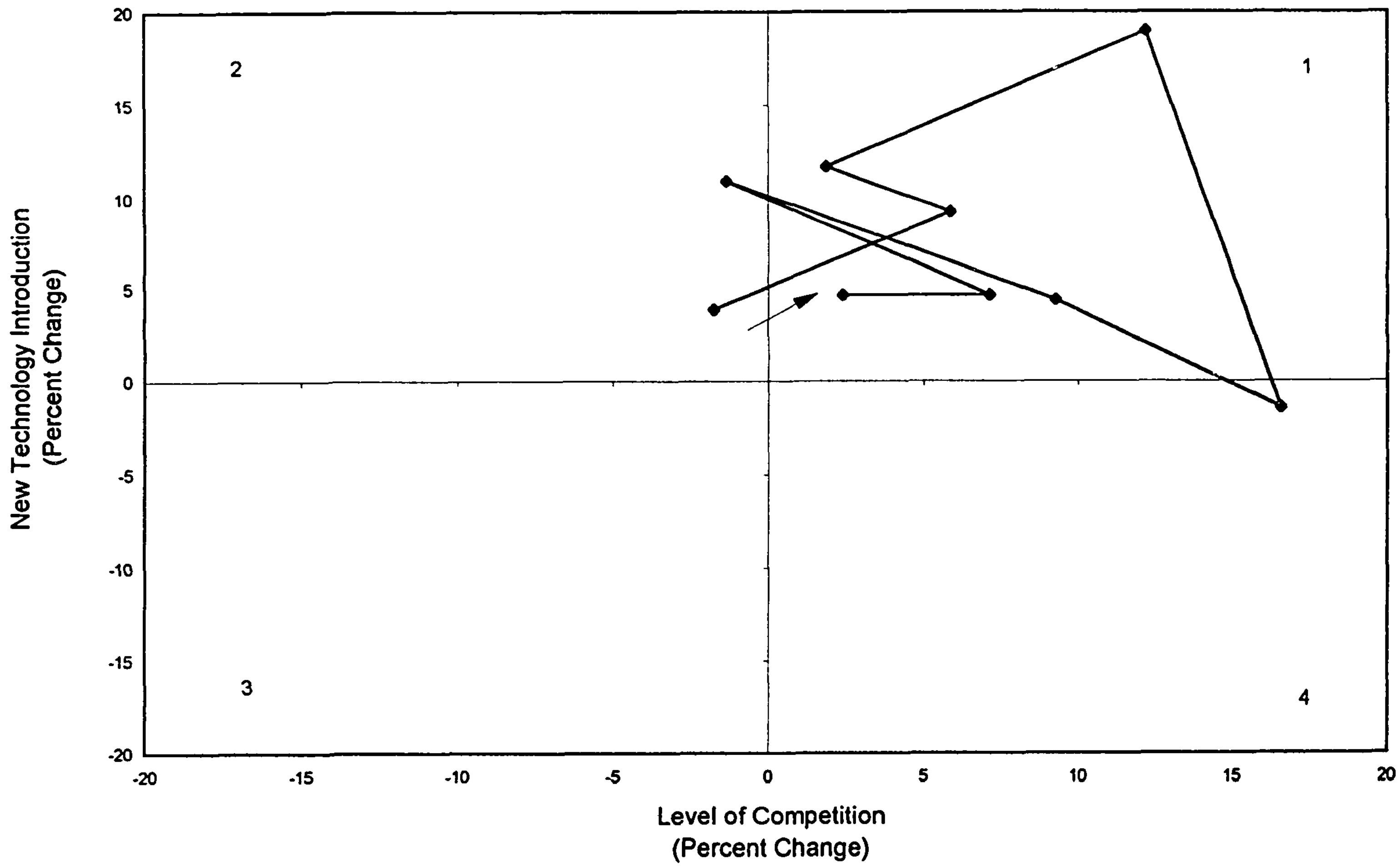
Phase Plane: NASA Support vs. Fed. Admin. Support (Filtered Data)



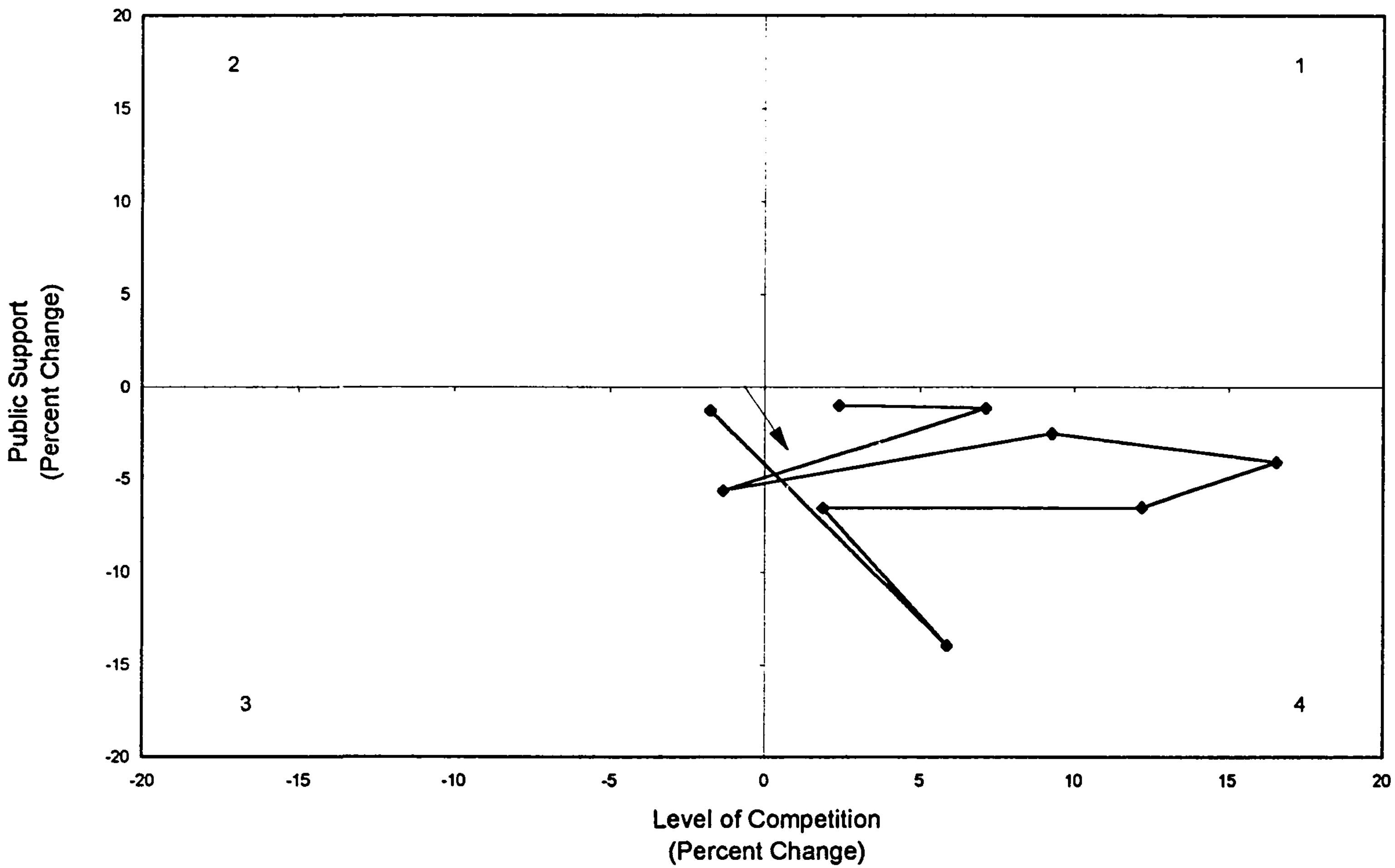
Phase Plane: DoD Support vs. Fed. Admin. Support (Filtered Data)



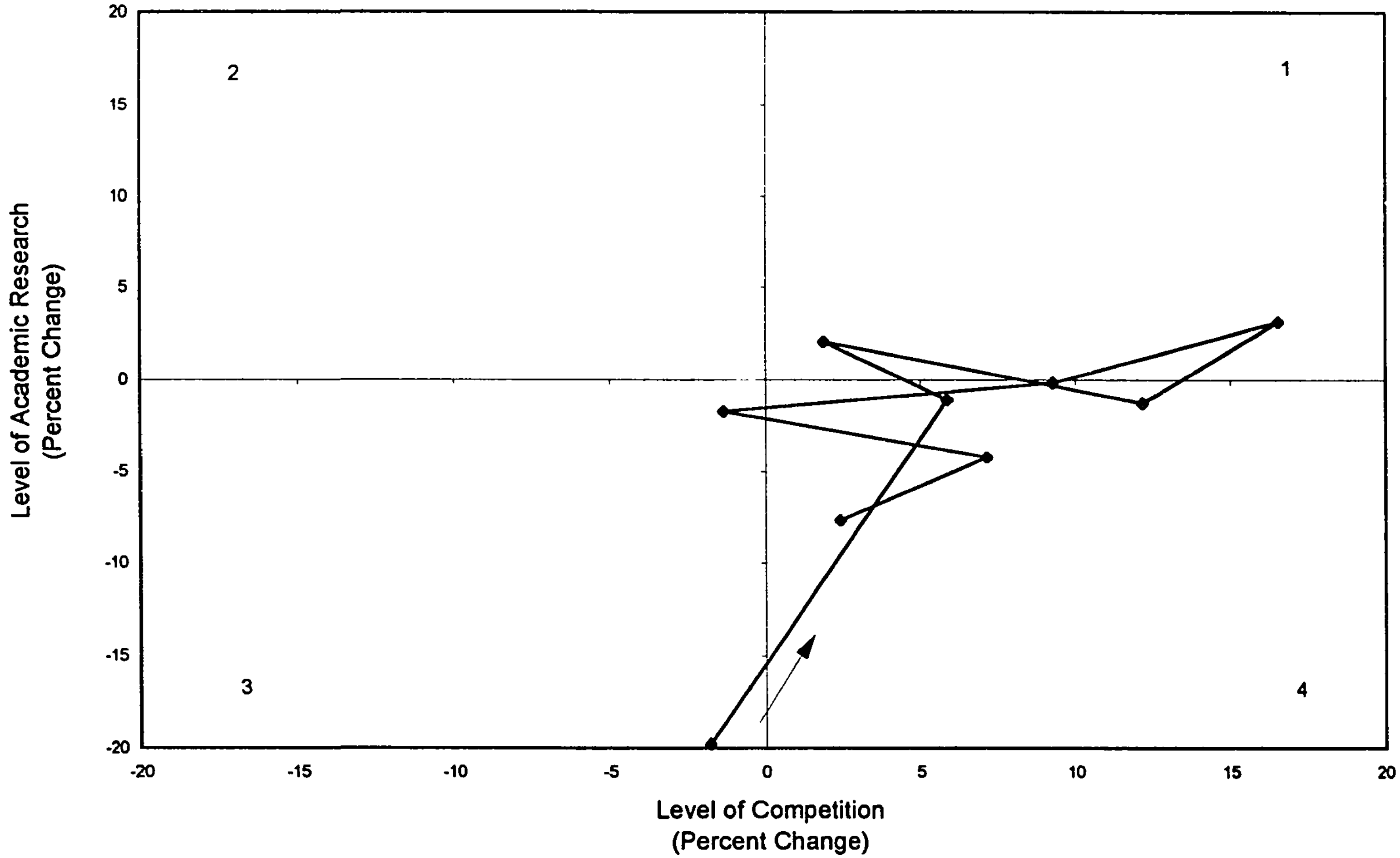
Phase Plane: New Technology vs. Competition (Filtered Data)



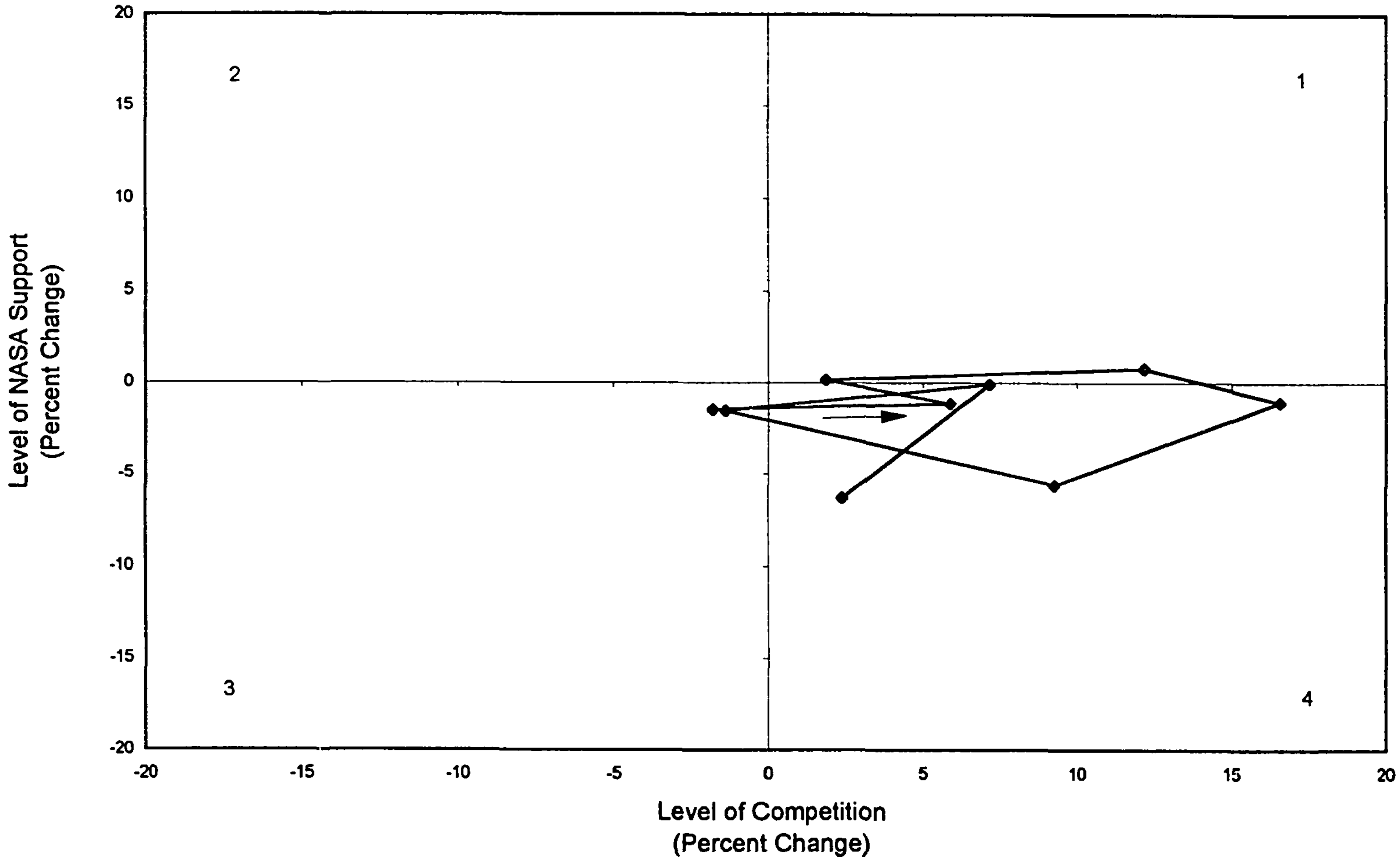
Phase Plane: Public Support vs. Competition (Filtered Data)



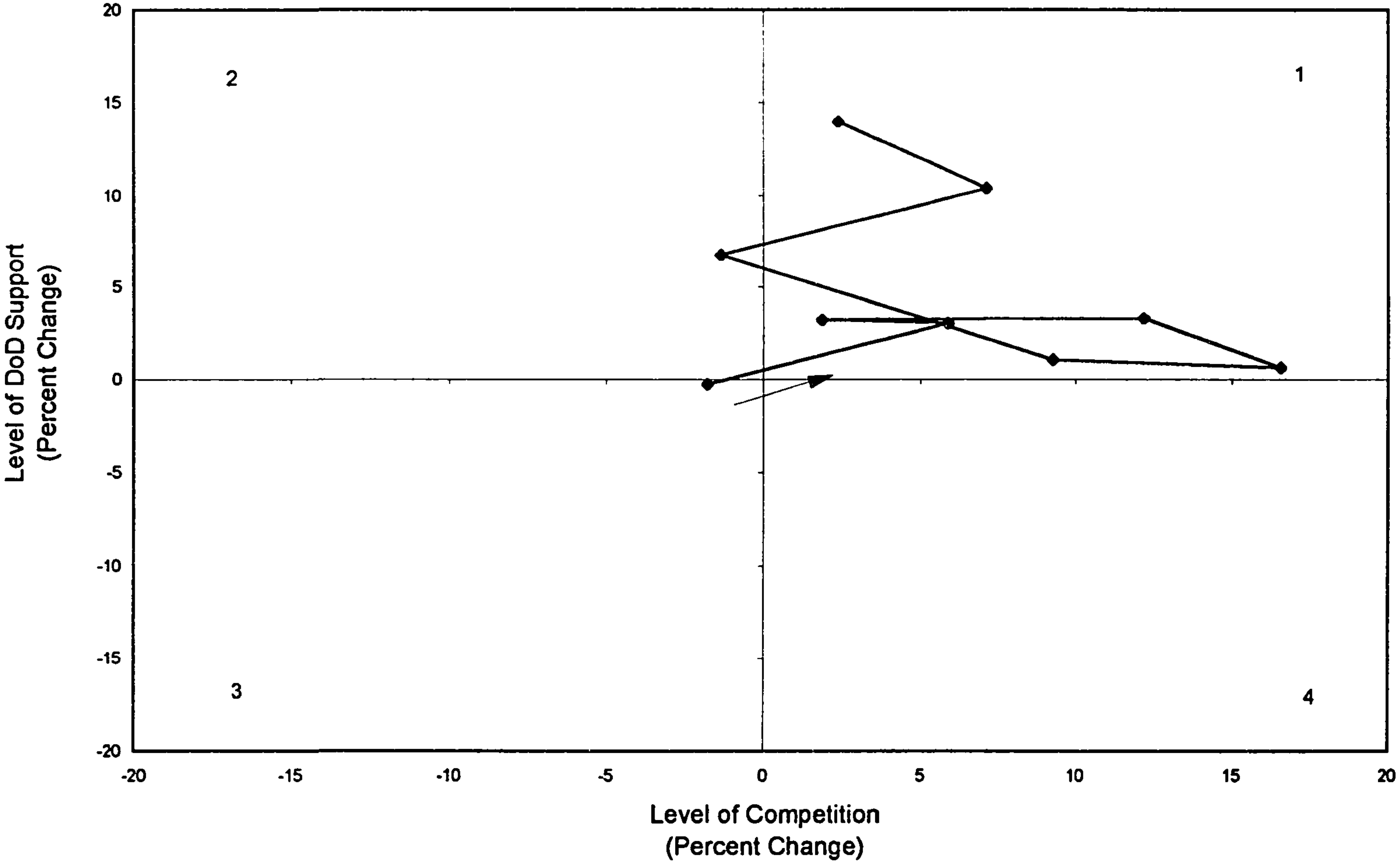
Phase Plane: Academic Research vs. Competition (Filtered Data)



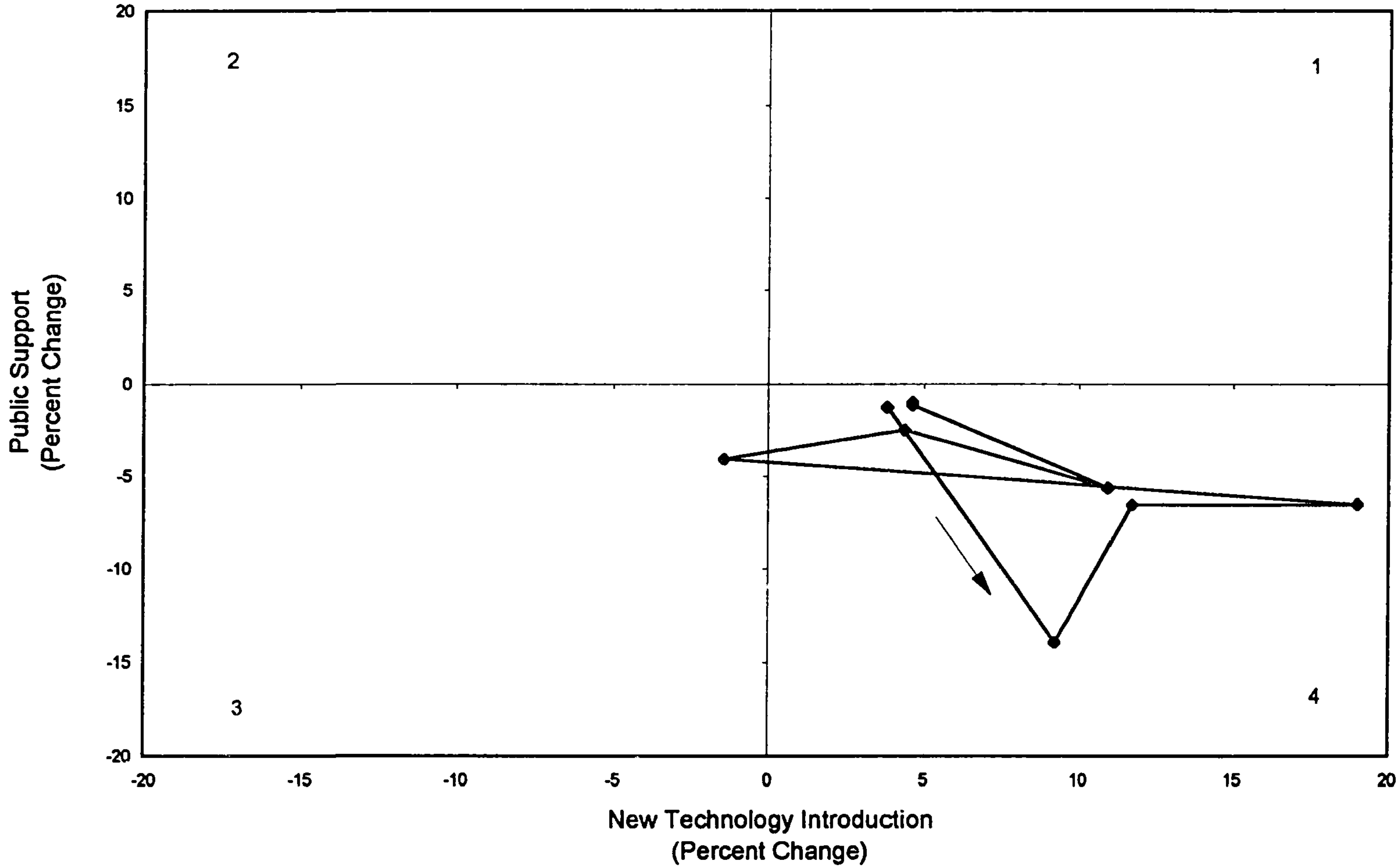
Phase Plane: NASA Support vs. Competition (Filtered Data)



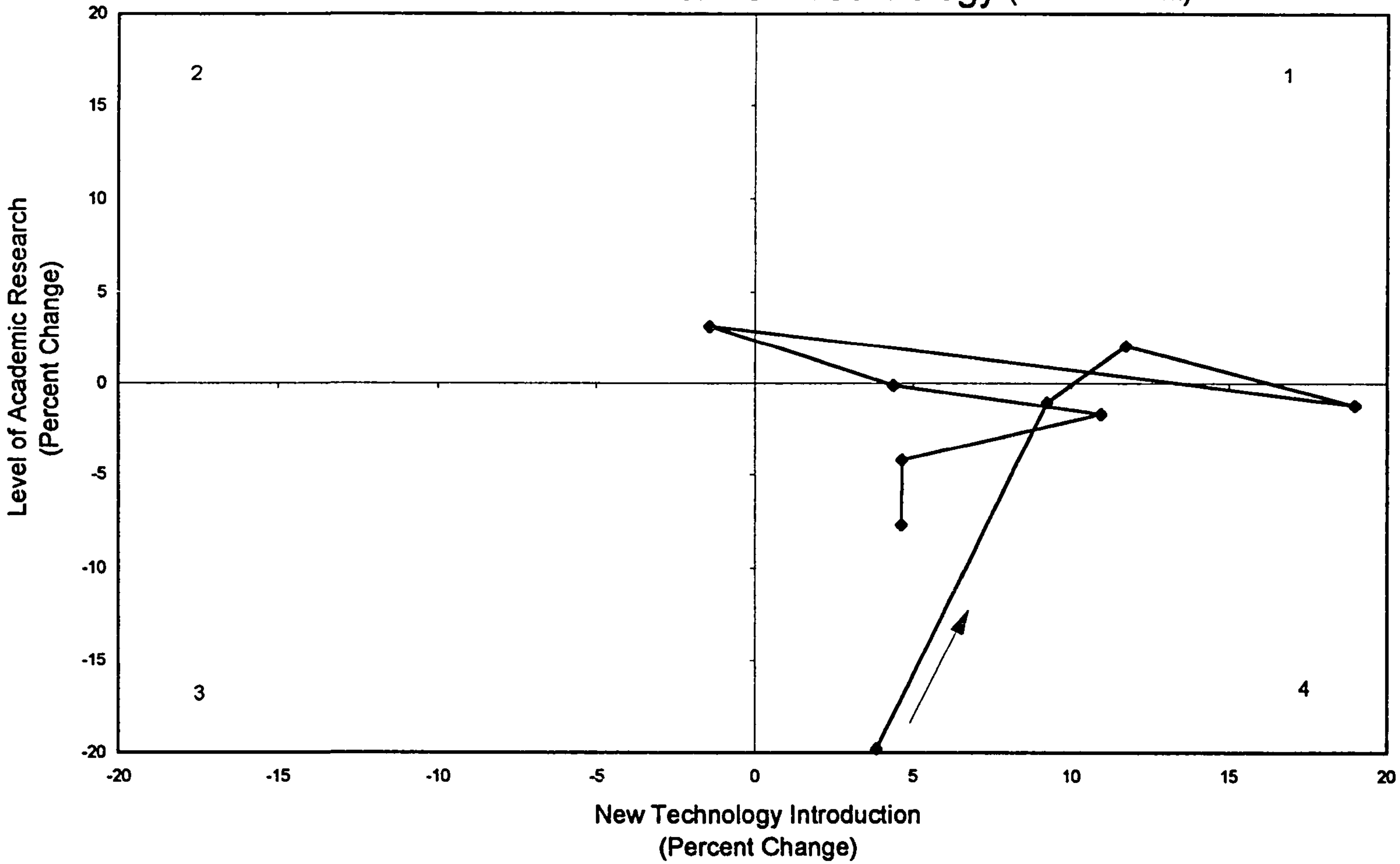
Phase Plane: DoD Support vs. Competition (Filtered Data)



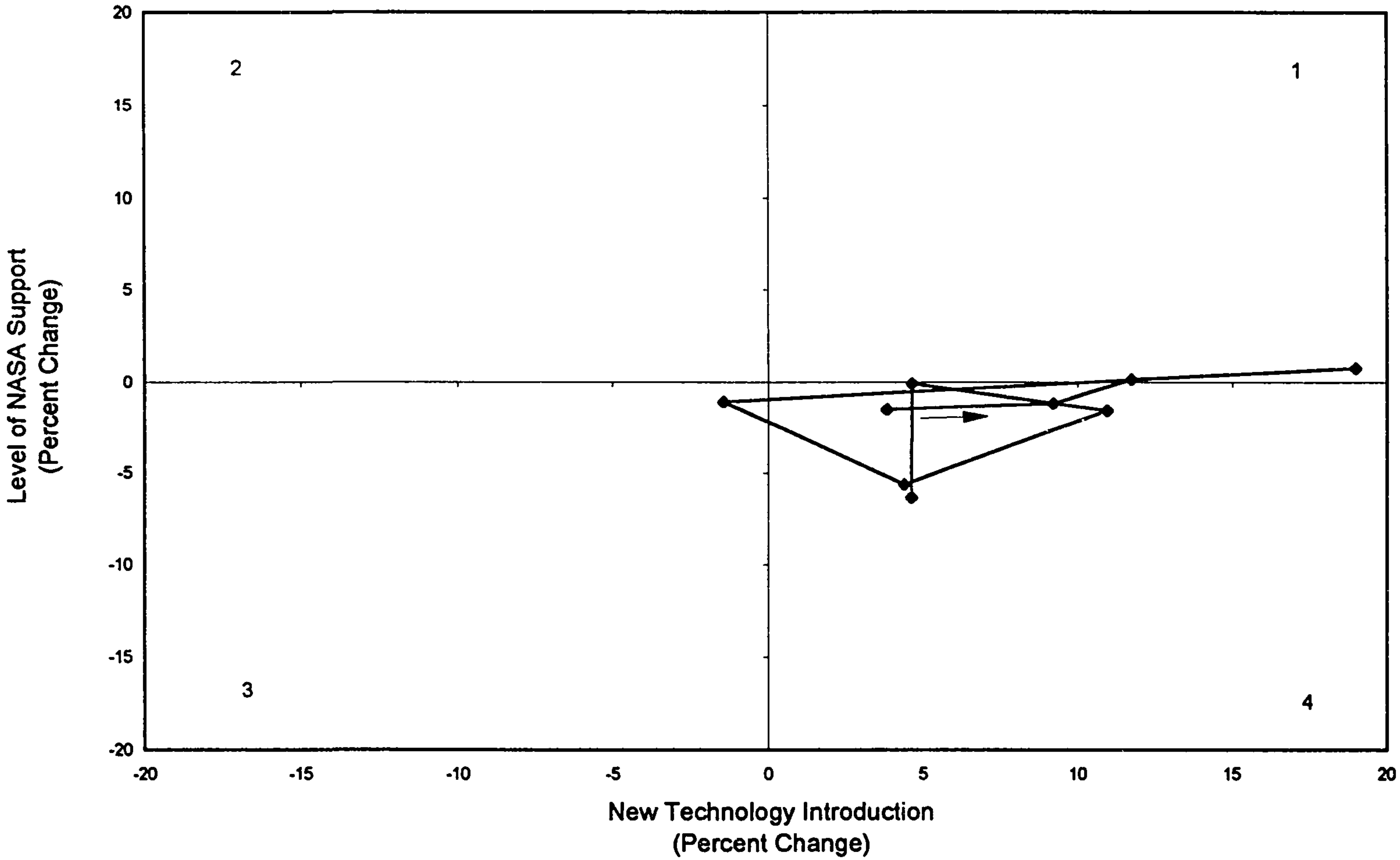
Phase Plane: Public Support vs. New Technology (Filtered Data)



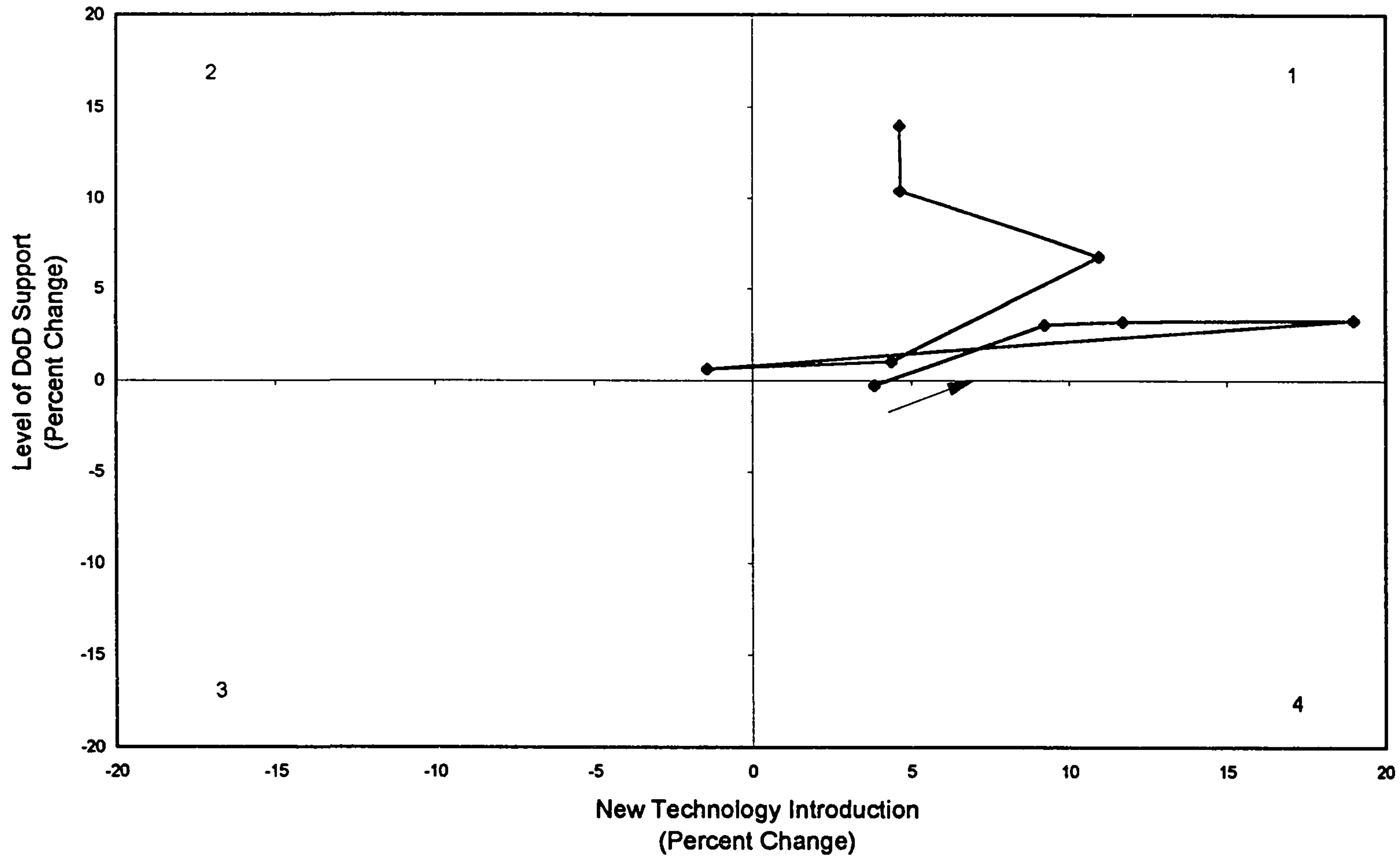
Phase Plane:
Academic Research vs. New Technology (Filtered Data)



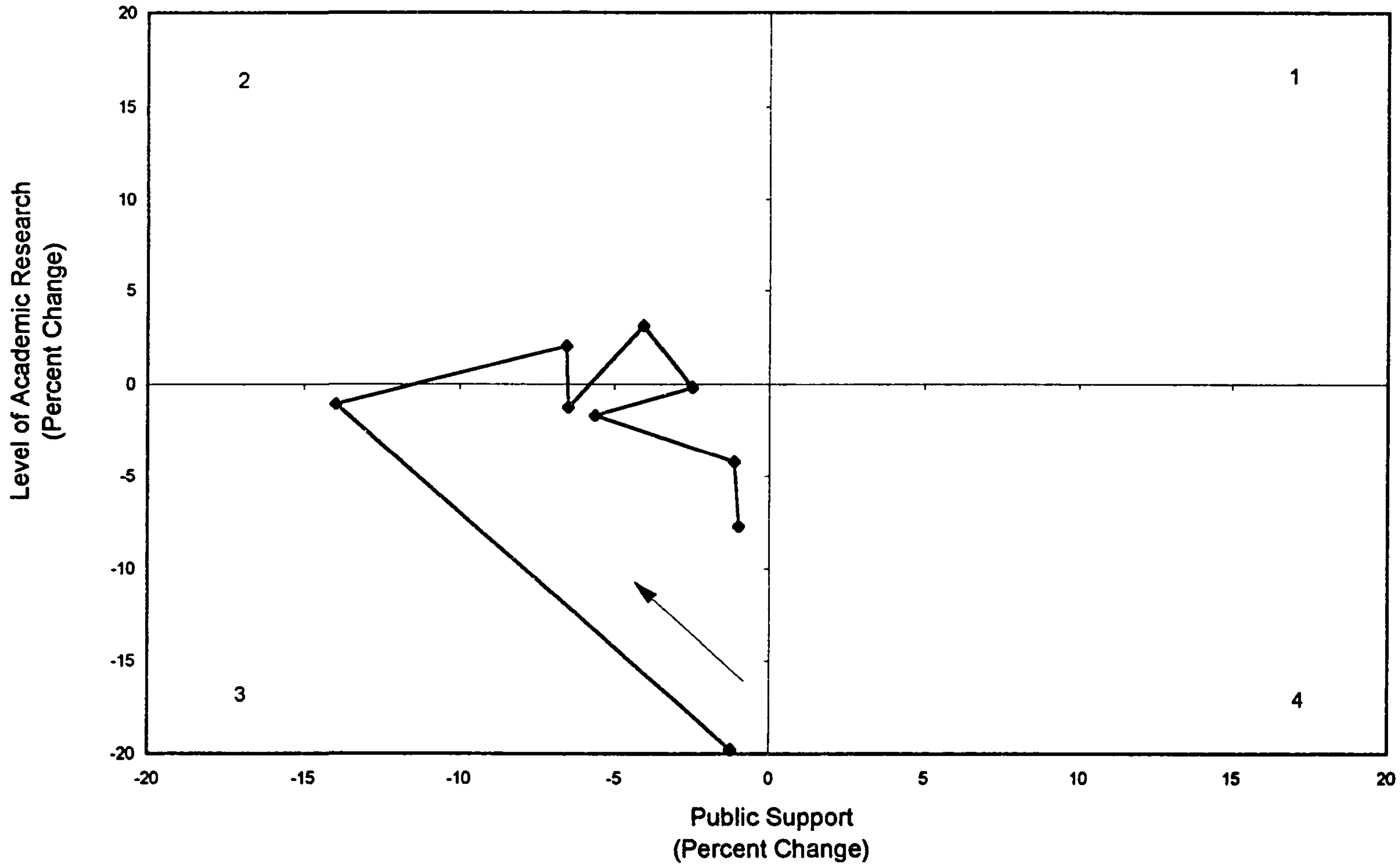
Phase Plane: NASA Support vs. New Technology (Filtered Data)



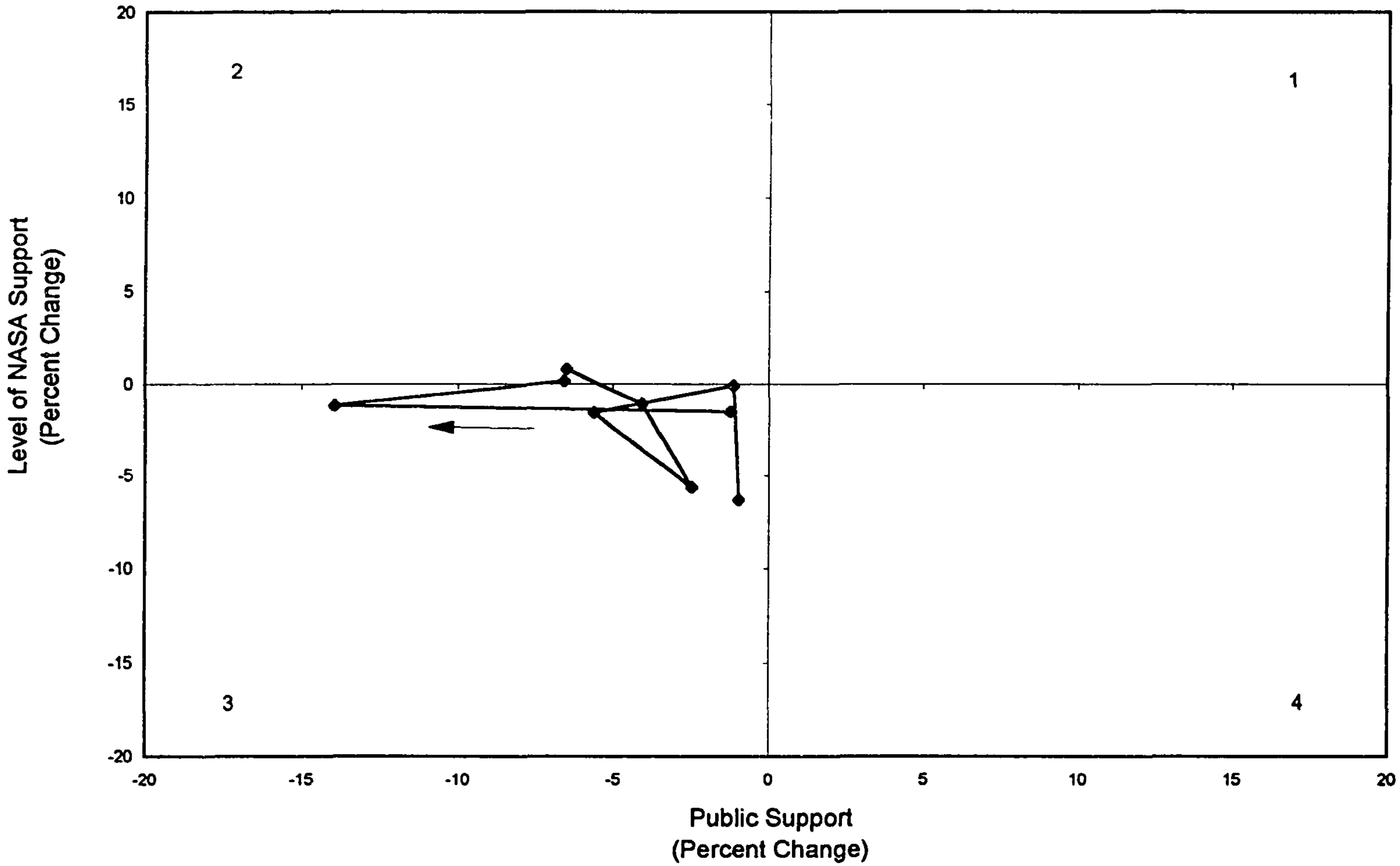
Phase Plane: DoD Support vs. New Technology (Filtered Data)



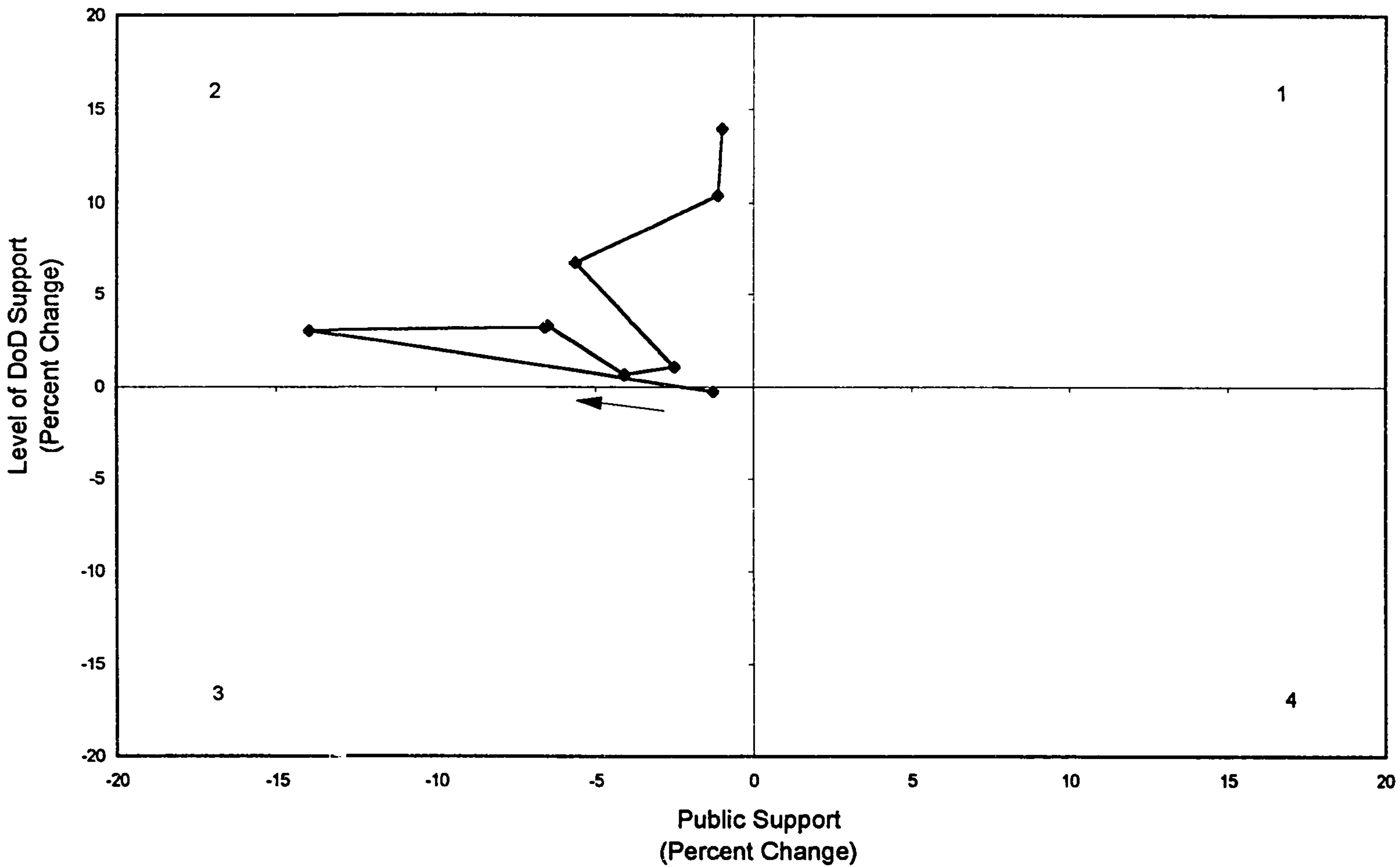
Phase Plane: Academic Research vs. Public Support (Filtered Data)



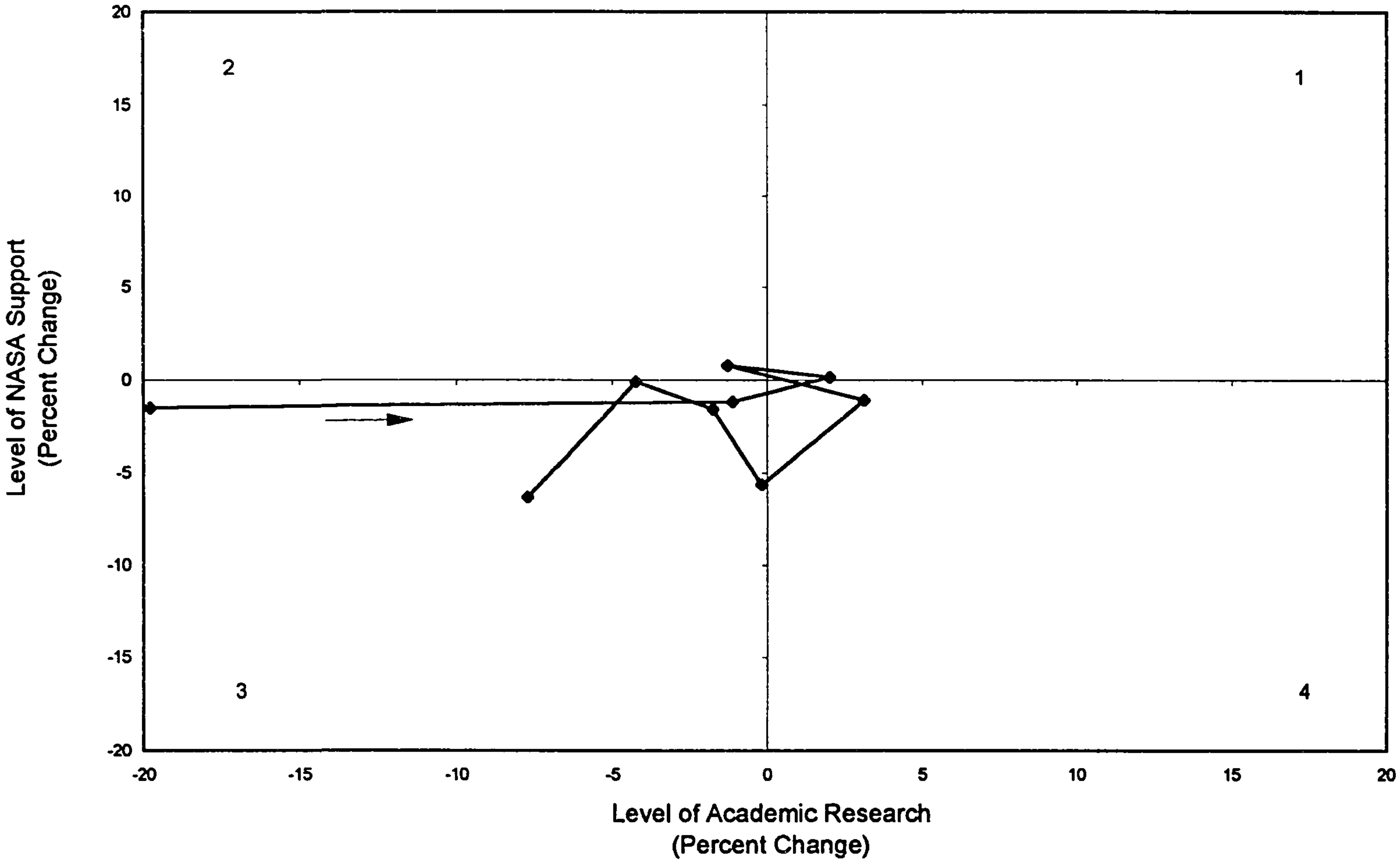
Phase Plane: NASA Support vs. Public Support (Filtered Data)



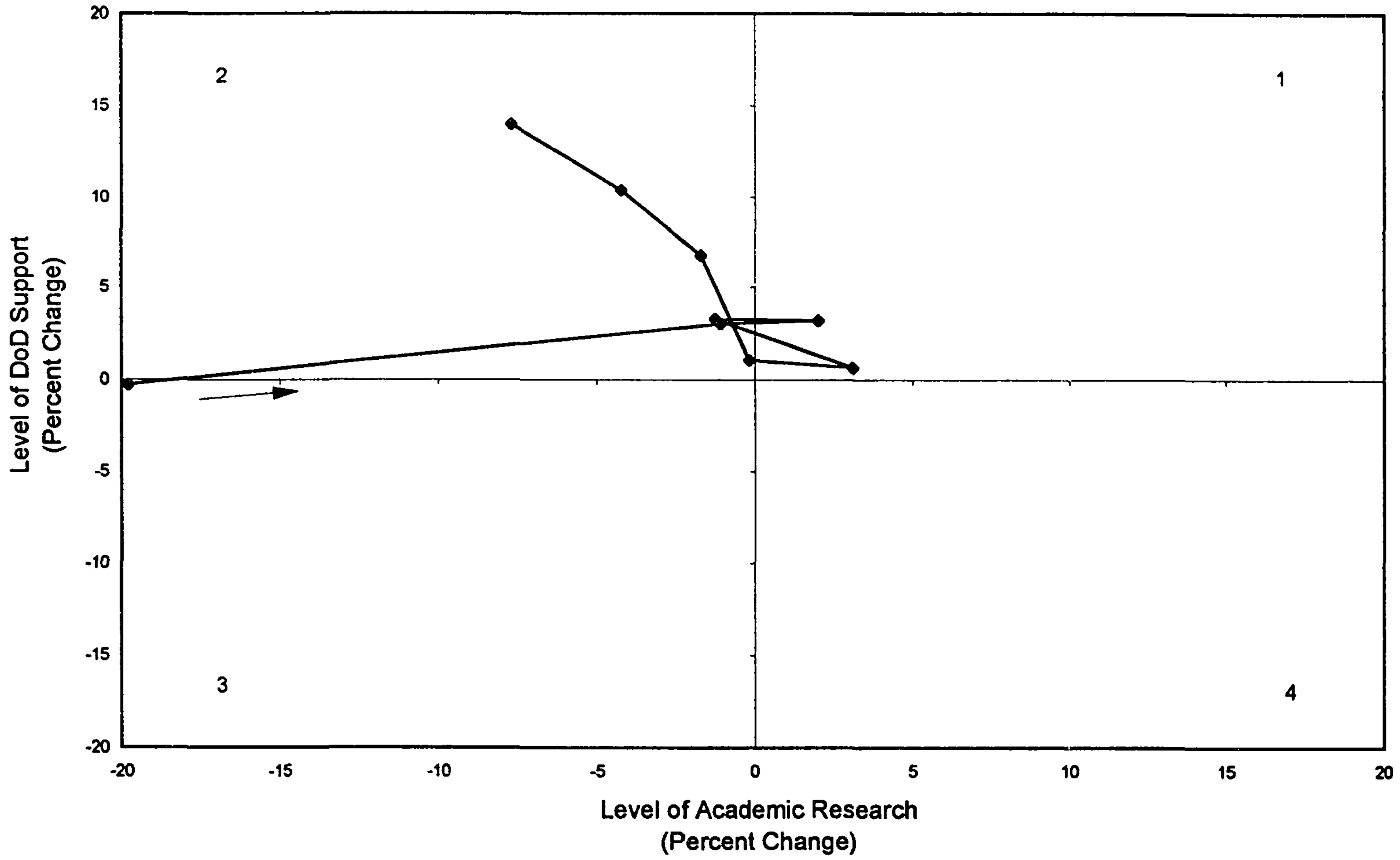
Phase Plane: DoD Support vs. Public Support (Filtered Data)



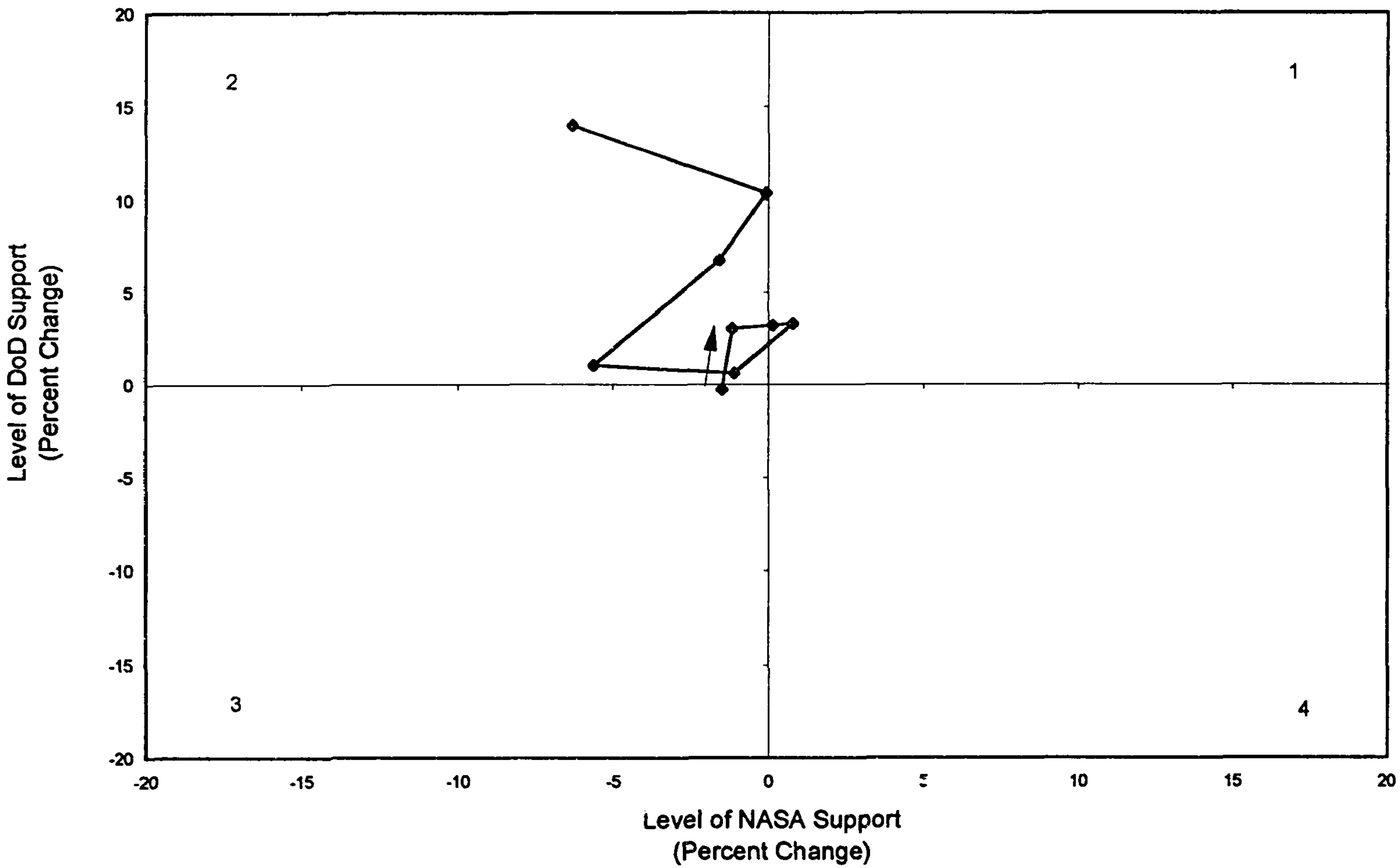
Phase Plane: NASA Support vs. Academic Research (Filtered Data)



Phase Plane: DoD Support vs.Academic Research (Filtered Data)



Phase Plane: DoD Support vs. NASA Support (Filtered Data)



APPENDIX G

PHASE PLANE ANALYSIS DATA

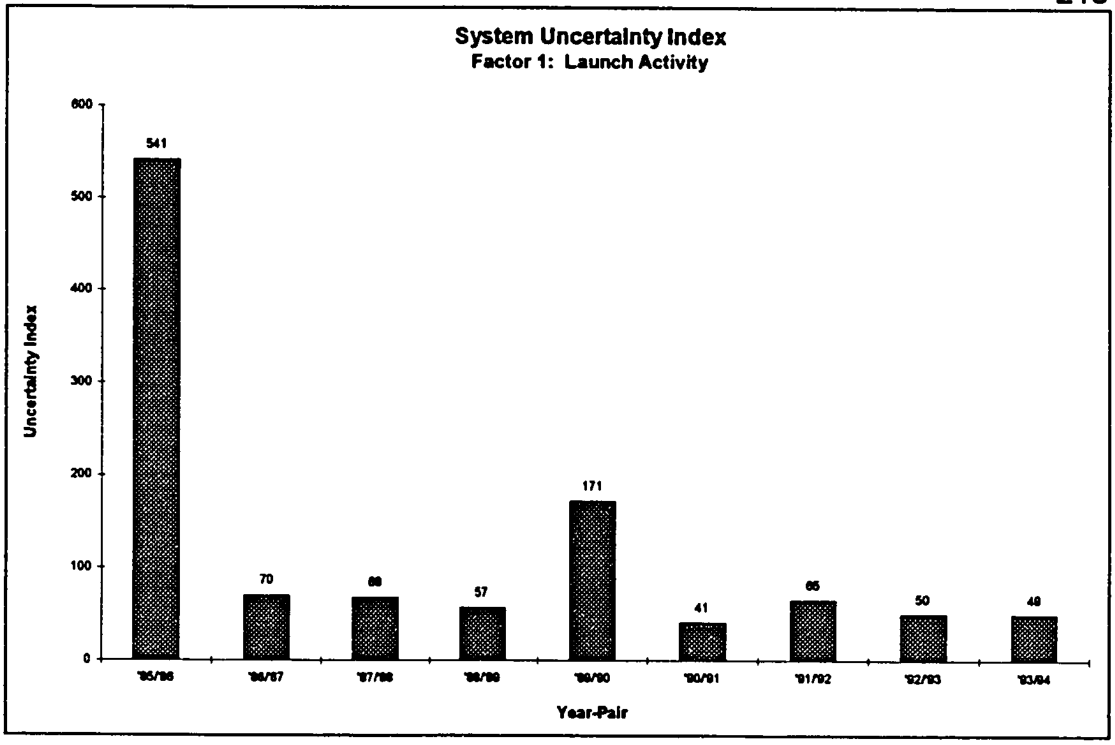
						Analysis of Phase Planes																		
													Periodicity						Projected Behavior					
		Factor Pair		Trajectory by Quadrant									Prior Four	Last Four	Rsrchr.		Resp 1		Resp 2		Resp 3		Resp 4	
1	Launch Cost	vs.	Launch Activity	3	3	4	4	1	1	1	1	2	8	2	OUT	1	OUT	1	OUT	2	OUT	1	OUT	1
2	Legal/Regulatory Environ.	vs.	Launch Activity	2	2	1	1	1	1	1	4	3	2	8	IN	2	OUT	2	OUT	2	OUT	4	OUT	4
3	Fed. Admin. Support	vs.	Launch Activity	2	2	1	1	1	4	1	4	3	2	8	OUT	3	OUT	3	OUT	3	OUT	4	OUT	4
4	Competition	vs.	Launch Activity	2	2	1	1	1	1	4	1	2	2	8	IN	4	OUT	1	OUT	3	IN	1	IN	3
5	New Technology	vs.	Launch Activity	2	2	1	1	4	1	1	1	2	8	2	OUT	1	OUT	2	OUT	2	OUT	1	OUT	1
6	Public Support	vs.	Launch Activity	3	3	4	4	4	4	4	4	3	2	2	OUT	3	OUT	3	OUT	3	OUT	4	OUT	1
7	Academic Research	vs.	Launch Activity	3	3	1	4	1	4	4	4	3	8	2	OUT	3	OUT	3	OUT	3	IN	4	OUT	4
8	NASA Support	vs.	Launch Activity	3	3	1	1	4	4	4	4	3	8	2	OUT	4	OUT	3	OUT	3	IN	4	OUT	4
9	DoD Support	vs.	Launch Activity	2	2	1	1	1	1	1	1	2	2	2	OUT	2	OUT	2	IN	2	IN	1	IN	1
10	Legal/Regulatory Environ.	vs.	Launch Cost	2	2	2	2	1	1	1	4	4	2	2	IN	1	IN	1	IN	1	IN	4	IN	1
11	Fed. Admin. Support	vs.	Launch Cost	2	2	2	2	1	4	1	4	4	2	8	OUT	4	OUT	4	OUT	4	IN	4	IN	1
12	Competition	vs.	Launch Cost	3	2	2	2	1	1	4	1	1	2	8	OUT	1	OUT	1	OUT	4	OUT	1	OUT	1
13	New Technology	vs.	Launch Cost	2	2	2	2	4	1	1	1	1	2	1	OUT	1	IN	4	OUT	1	OUT	1	OUT	1
14	Public Support	vs.	Launch Cost	3	3	3	3	4	4	4	4	4	2	1	OUT	4	OUT	4	OUT	1	IN	4	OUT	4
15	Academic Research	vs.	Launch Cost	3	3	2	3	1	4	4	4	4	8	1	OUT	4	OUT	4	OUT	4	OUT	4	OUT	4
16	NASA Support	vs.	Launch Cost	3	3	2	2	4	4	4	4	4	8	1	OUT	4	OUT	4	OUT	4	IN	4	OUT	4
17	DoD Support	vs.	Launch Cost	3	2	2	2	1	1	1	1	1	2	1	OUT	1	IN	1	OUT	1	OUT	1	OUT	1
18	Fed. Admin. Support	vs.	Legal/Regulatory Environ.	1	1	1	1	1	4	1	3	3	1	8	IN	4	IN	3	OUT	3	IN	3	IN	2
19	Competition	vs.	Legal/Regulatory Environ.	4	1	1	1	1	1	4	2	2	1	8	IN	3	OUT	2	OUT	2	OUT	2	OUT	2
20	New Technology	vs.	Legal/Regulatory Environ.	1	1	1	1	4	1	1	2	2	2	2	OUT	1	OUT	2	IN	2	OUT	1	IN	2
21	Public Support	vs.	Legal/Regulatory Environ.	4	4	4	4	4	4	4	3	3	1	2	IN	3	OUT	3	IN	3	OUT	3	IN	3
22	Academic Research	vs.	Legal/Regulatory Environ.	4	4	1	4	1	4	4	3	3	2	2	OUT	4	IN	2	IN	4	IN	4	IN	4
23	NASA Support	vs.	Legal/Regulatory Environ.	4	4	1	1	4	4	4	3	3	2	2	OUT	4	IN	2	IN	4	IN	4	IN	3
24	DoD Support	vs.	Legal/Regulatory Environ.	4	1	1	1	1	1	1	2	2	1	2	OUT	2	IN	2	OUT	1	IN	2	IN	2
25	Competition	vs.	Fed. Admin. Support	4	1	1	1	1	2	4	2	2	1	2	OUT	3	IN	3	OUT	2	IN	3	OUT	2
26	New Technology	vs.	Fed. Admin. Support	1	1	1	1	4	2	1	2	2	2	2	OUT	2	OUT	2	OUT	2	IN	2	OUT	2
27	Public Support	vs.	Fed. Admin. Support	4	4	4	4	4	3	4	3	3	1	2	OUT	3	IN	3	OUT	3	IN	3	IN	4
28	Academic Research	vs.	Fed. Admin. Support	4	4	1	4	1	3	4	3	3	2	2	OUT	3	OUT	3	IN	3	IN	3	OUT	3
29	NASA Support	vs.	Fed. Admin. Support	4	4	1	1	4	3	4	3	3	2	2	OUT	3	IN	3	IN	3	IN	3	IN	3
30	DoD Support	vs.	Fed. Admin. Support	4	1	1	1	1	2	1	2	2	1	2	OUT	2	OUT	2	OUT	2	OUT	2	IN	2
31	New Technology	vs.	Competition	2	1	1	1	4	1	2	1	1	2	2	IN	1	OUT	4	OUT	1	OUT	1	OUT	1
32	Public Support	vs.	Competition	3	4	4	4	4	4	3	4	4	1	2	IN	3	OUT	3	OUT	4	OUT	4	IN	4

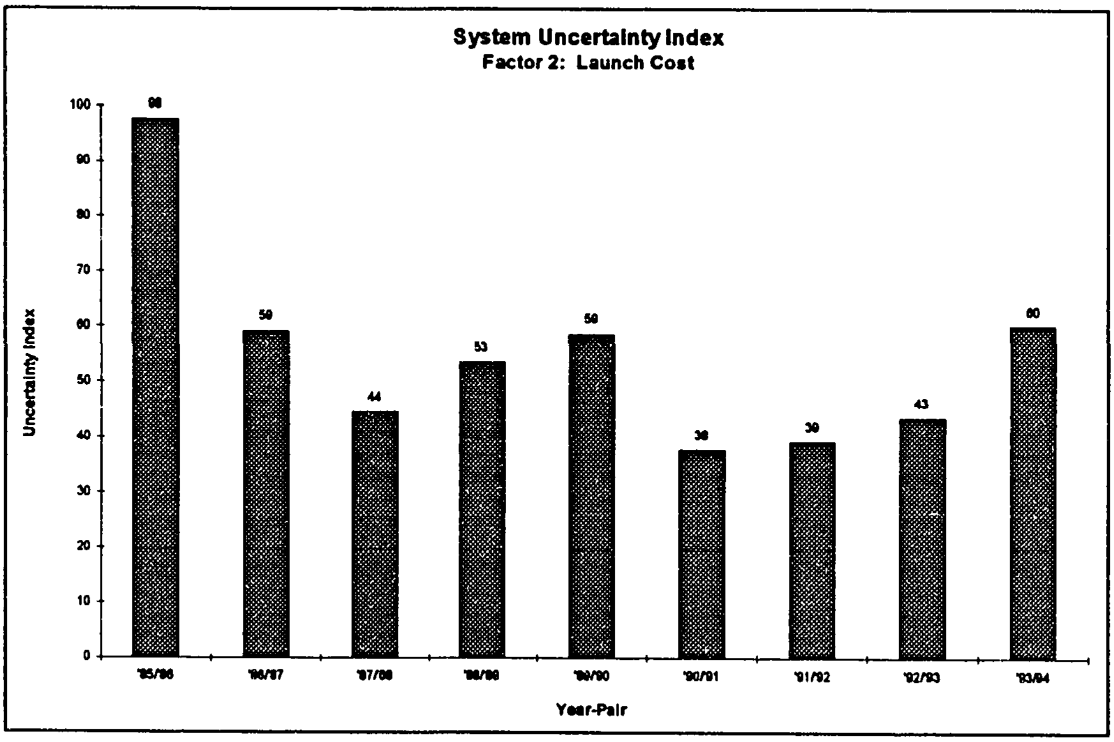
Analysis of Phase Planes

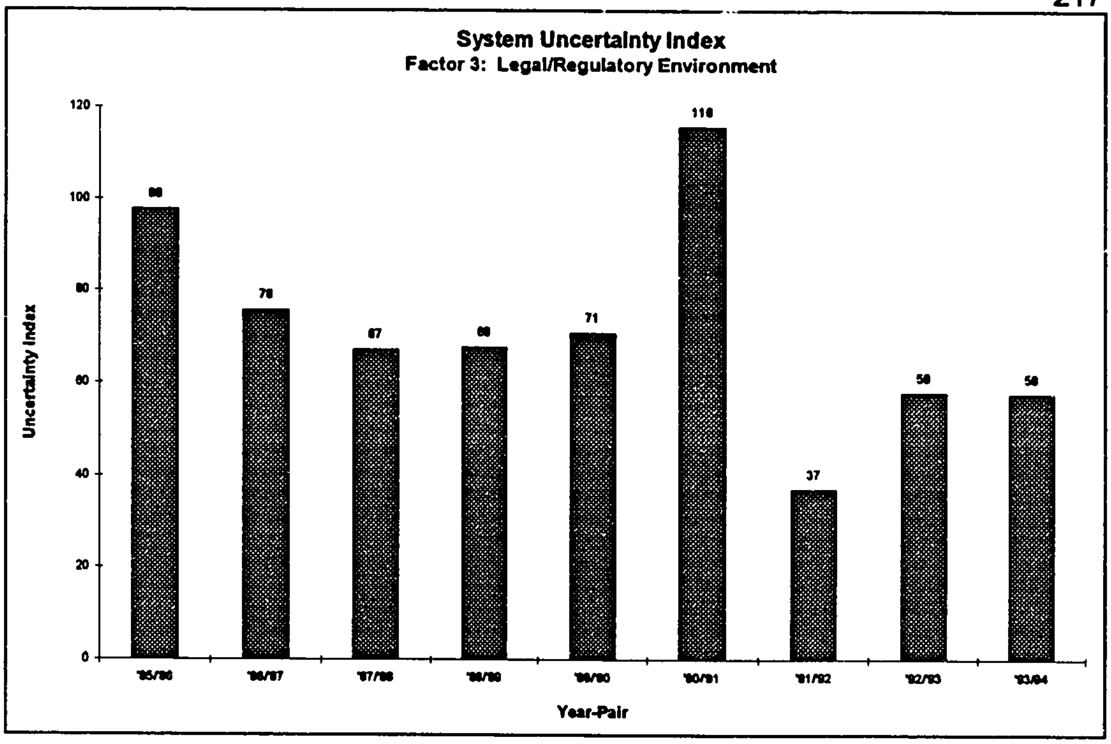
	Factor Pair			Trajectory by Quadrant									Periodicity				Projected Behavior							
													Prior Four	Last Four	Rsrchr.		Resp 1		Resp 2		Resp 3		Resp 4	
33	Academic Research	vs.	Competition	3	4	1	4	1	4	3	4	4	2	2	OUT	4	OUT	4	OUT	4	OUT	4	OUT	4
34	NASA Support	vs.	Competition	3	4	1	1	4	4	3	4	4	2	2	IN	3	OUT	4	OUT	4	OUT	4	OUT	4
35	DoD Support	vs.	Competition	3	1	1	1	1	1	2	1	1	1	2	OUT	1	OUT	1	OUT	1	OUT	1	OUT	1
36	Public Support	vs.	New Technology	4	4	4	4	3	4	4	4	4	2	1	IN	4	OUT	4	OUT	4	OUT	4	OUT	4
37	Academic Research	vs.	New Technology	4	4	1	4	2	4	4	4	4	8	1	OUT	4	OUT	1	OUT	4	OUT	4	OUT	4
38	NASA Support	vs.	New Technology	4	4	1	1	3	4	4	4	4	8	1	OUT	4	OUT	4	OUT	4	OUT	4	OUT	4
39	DoD Support	vs.	New Technology	4	1	1	1	2	1	1	1	1	2	1	OUT	1	OUT	1	OUT	1	OUT	1	IN	1
40	Academic Research	vs.	Public Support	3	3	2	3	1	3	3	3	3	8	1	OUT	3	OUT	2	OUT	3	IN	3	IN	3
41	NASA Support	vs.	Public Support	3	3	2	2	3	3	3	3	3	2	1	OUT	3	OUT	3	OUT	2	IN	3	IN	3
42	DoD Support	vs.	Public Support	3	2	2	2	2	2	2	2	2	1	1	OUT	2	OUT	2	OUT	2	OUT	2	IN	2
43	NASA Support	vs.	Academic Research	3	3	1	2	4	3	3	3	3	4	1	OUT	3	OUT	3	OUT	3	OUT	3	IN	3
44	DoD Support	vs.	Academic Research	3	2	1	2	1	2	2	2	2	2	1	OUT	2	OUT	2	OUT	2	OUT	2	IN	2
45	DoD Support	vs.	NASA Support	3	2	1	1	2	2	2	2	2	2	1	OUT	2	OUT	2	OUT	2	IN	2	IN	2

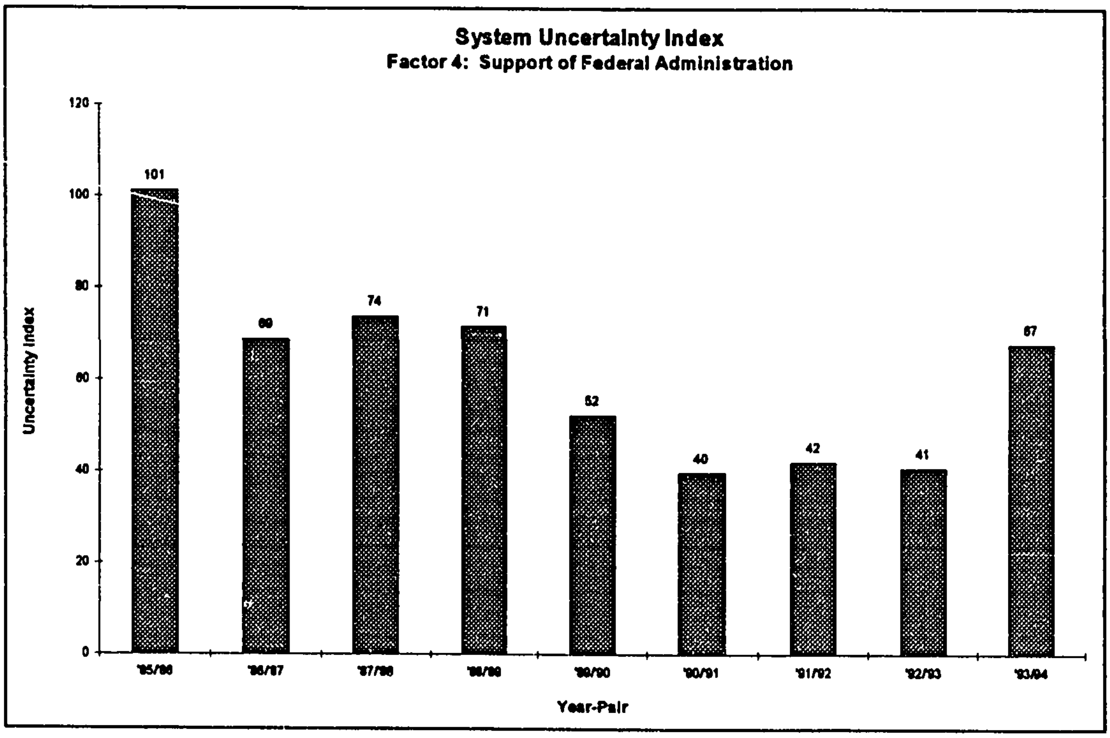
APPENDIX H

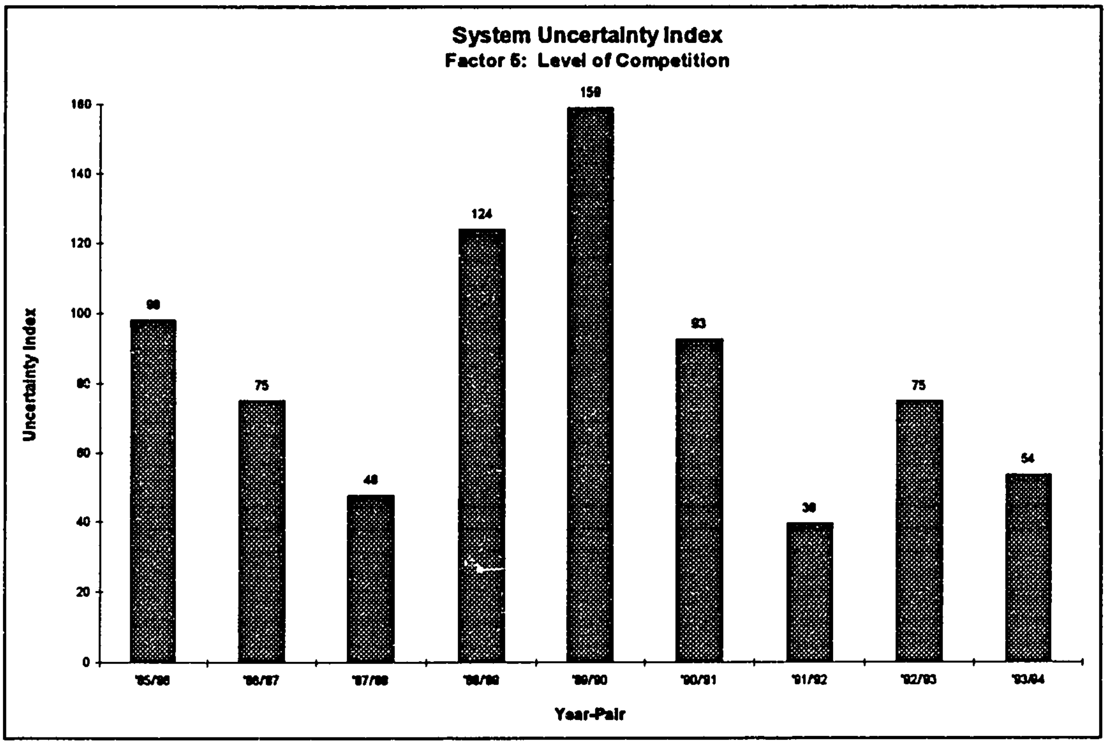
SYSTEM UNCERTAINTY INDEX CHARTS FOR INDIVIDUAL FACTORS

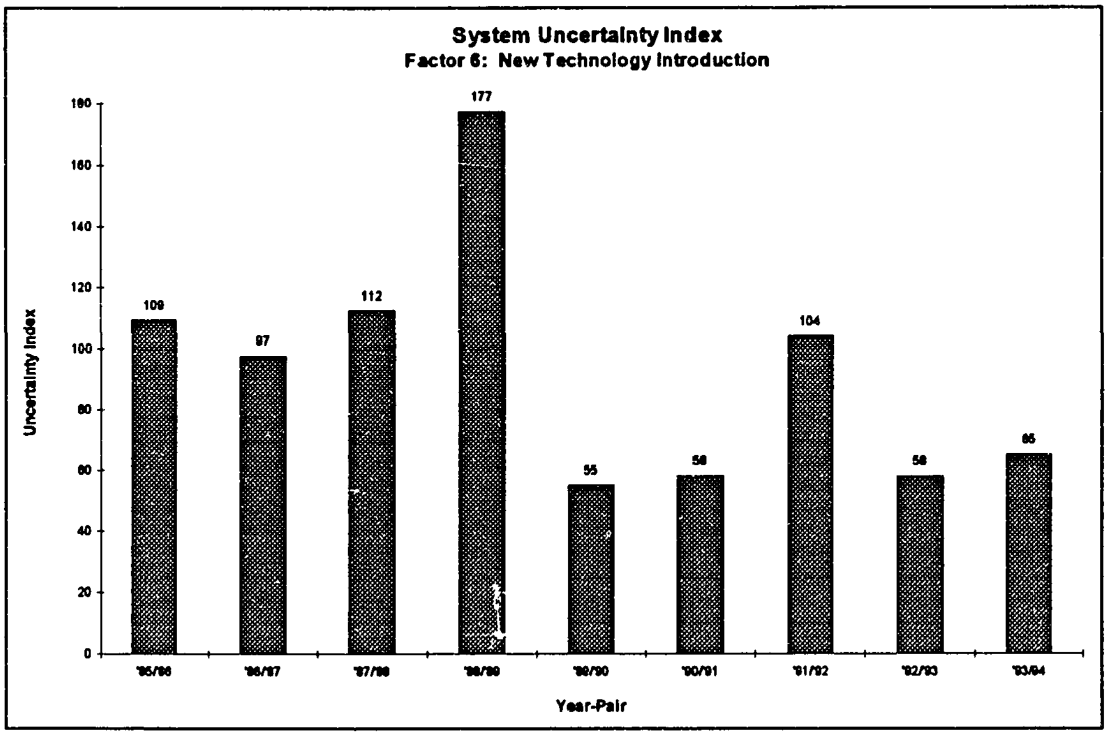

System Uncertainty Index
Factor 1: Launch Activity
Uncertainty Index
600
500
400
300
200
100
0
541
70
57
171
41
50
'86/87
'90/91
'91/92
'92/93
'93/94
Year-Pair

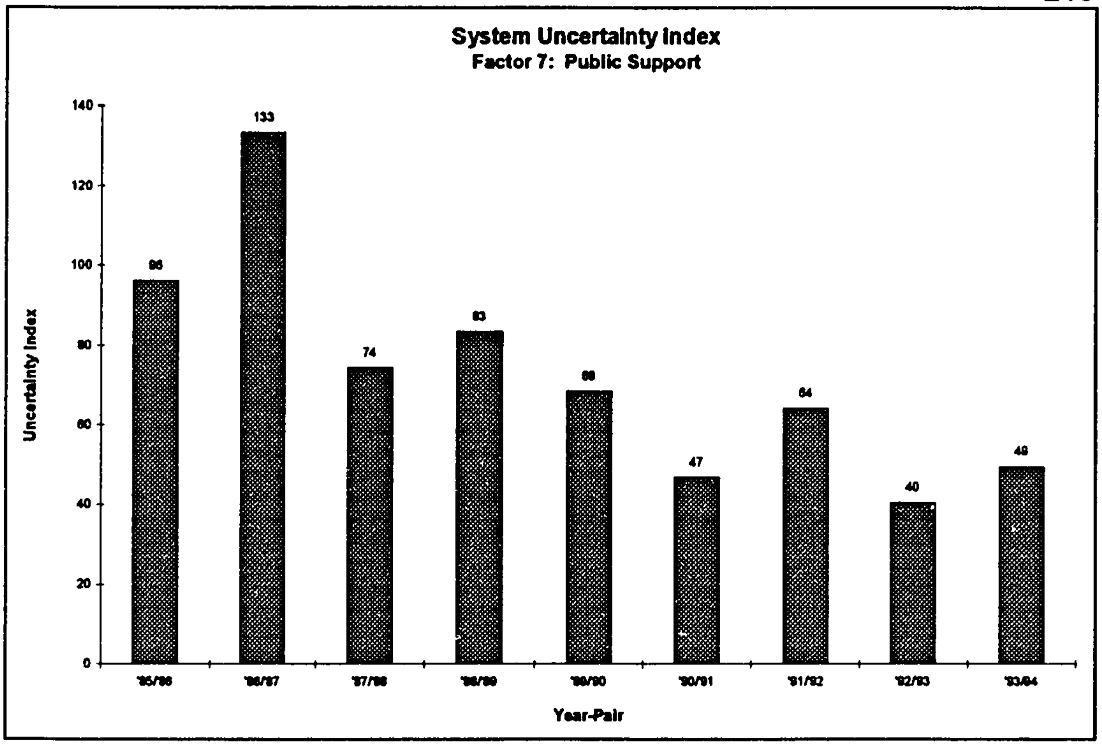

System Uncertainty Index
Factor 2: Launch Cost
Uncertainty Index
100
90
80
70
60
50
40
30
20
10
0
44
53
43
'90/91
'91/92
'92/93
'93/94
Year-Pair

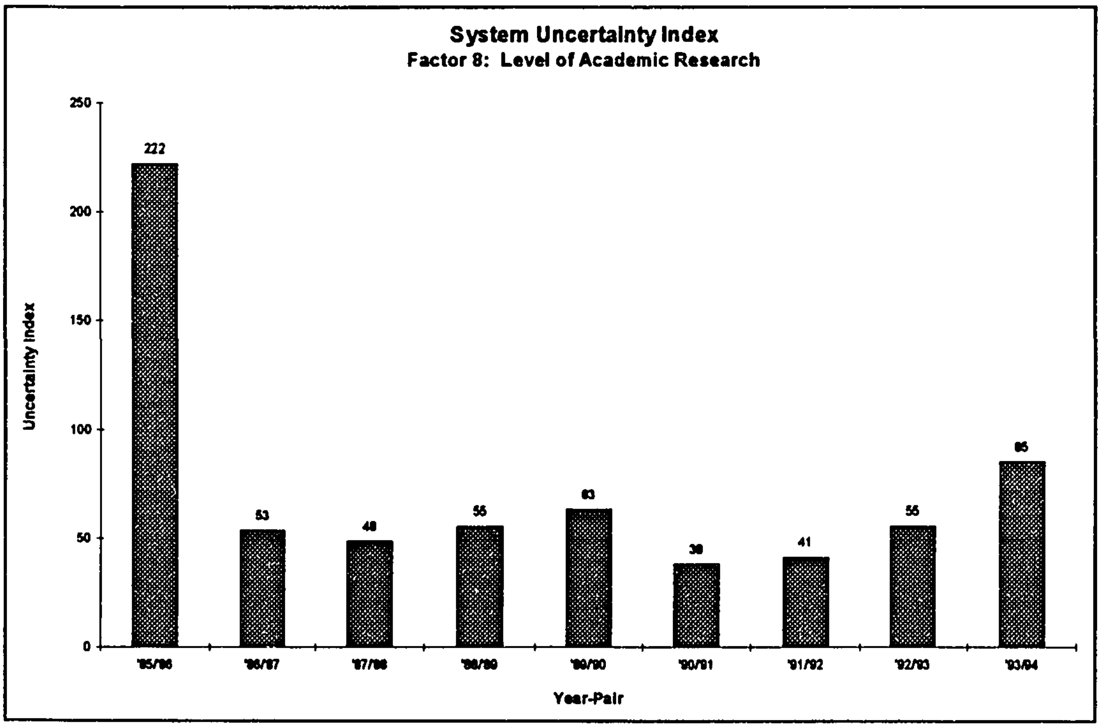

System Uncertainty Index
Factor 3: Legal/Regulatory Environment
Uncertainty Index
120
100
80
60
40
20
0
71
37
'90/91
'91/92
'92/93
'93/94
Year-Pair

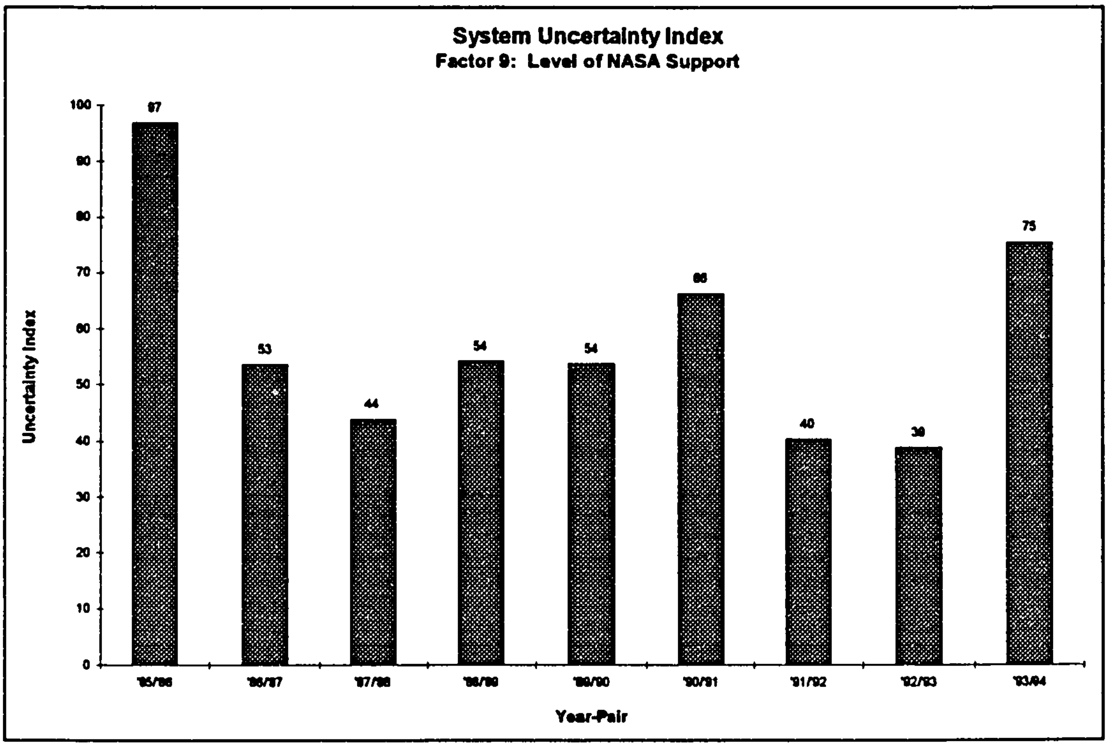

System Uncertainty Index
Factor 4: Support of Federal Administration
Uncertainty Index
120
100
80
60
40
20
0
101
74
71
52
40
42
41
67
'85/86
'86/87
'87/88
'89/90
'90/91
'91/92
'92/93
'93/94
Year-Pair

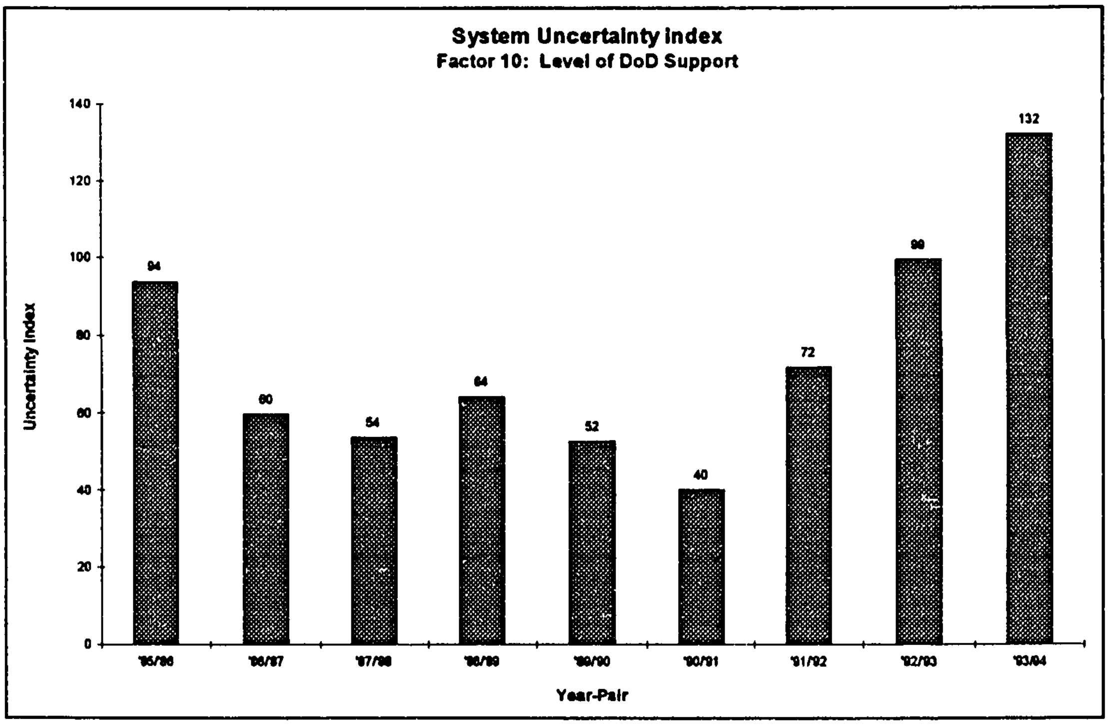

System Uncertainty Index
Factor 5: Level of Competition
Uncertainty Index
0
20
40
60
80
100
120
140
160
124
159
93
75
75
54
'90/91
'91/92
'92/93
'93/94
Year-Pair


System Uncertainty Index
Factor 6: New Technology Introduction
Uncertainty Index
0
20
40
60
80
100
120
140
160
180
109
97
112
177
55
104
'90/91
'91/92
'92/93
'93/94
Year-Pair


System Uncertainty Index
Factor 7: Public Support
Uncertainty Index
140
120
100
80
60
40
20
0
133
96
74
47
64
40
Year-Pair
'90/91
'91/92
'92/93
'93/94

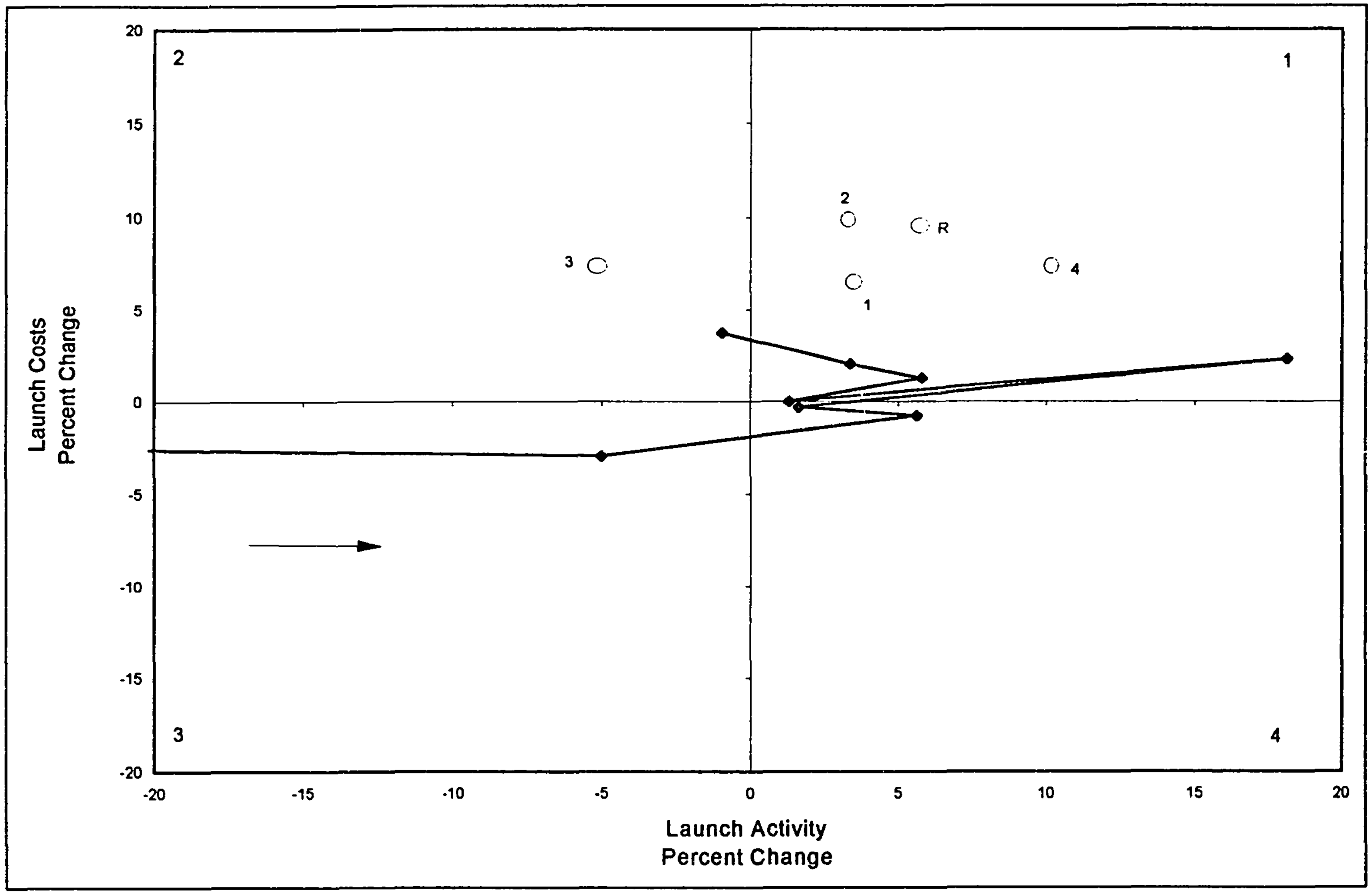

System Uncertainty Index
Factor 8: Level of Academic Research
Uncertainty Index
250
200
150
100
50
0
222
53
41
55
Year-Pair
'90/91
'91/92
'92/93
'93/94


System Uncertainty Index
Factor 9: Level of NASA Support
Uncertainty Index
100
90
80
70
60
50
40
30
20
10
0
97
53
44
54
54
66
40
39
75
'85/86
'86/87
'87/88
'88/89
'89/90
'90/91
'91/92
'92/93
'93/94
Year-Pair

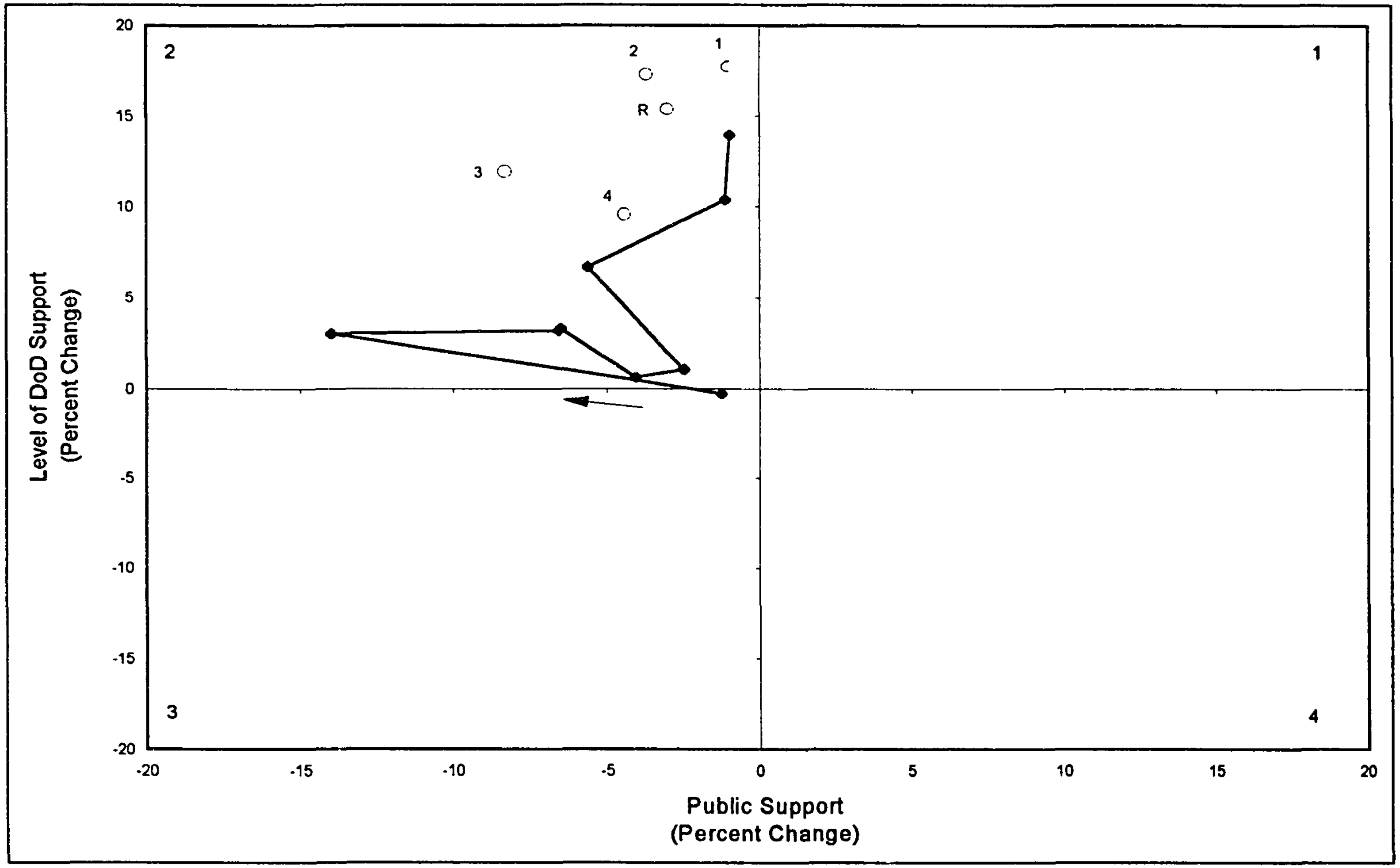

System Uncertainty Index
Factor 10: Level of DoD Support
Uncertainty Index
140
120
100
80
60
40
20
0
94
60
54
64
52
40
72
99
132
'85/86
'86/87
'87/88
'88/89
'89/90
'90/91
'91/92
'92/93
'93/94
Year-Pair

APPENDIX I

PHASE PLANE DIAGRAMS WITH "NEXT POINT" PROJECTIONS



Launch Cost/Launch Activity Phase Plane With "Next Point" Projections



Public Support/DoD Support Phase Plane With "Next Point" Projections

AUTOBIOGRAPHICAL STATEMENT

Wayne Woodhams was born on April 3, 1944 in Jamaica, New York. He received a Bachelor of Science in Electrical Engineering from Clarkson College of Technology (now Clarkson University) in 1968 and a Master of Business Administration (granted "with distinction" for academic achievement) from Adelphi University in 1972. Following his baccalaureate studies, Mr. Woodhams embarked on a 24 year career as an engineer and manager in the aerospace industry, wherein he performed as a Design Engineer and Project Manager for a large aircraft manufacturer, and as a Project Engineer, Program Manager and Director of Operations for a mid-sized support services contractor.

In 1992, Mr. Woodhams came to Old Dominion University as a Research Associate and Assistant Director of the Center for Commercial Space Infrastructure in the Department of Engineering Management. In 1993, he assumed a faculty position as Instructor. He is a current member of the Phi Kappa Phi Honor Society.