THE UNIVERSITY OF CALGARY

THE SOCIAL BASIS OF PETROLEUM RESOURCE ASSESSMENT

BY

GARY LEE BOWDEN

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR

DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF SOCIOLOGY

CALGARY, ALBERTA

THE UNIVERSITY OF CALGARY

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "The Social Basis of Petroleum Resource Assessment," submitted by Gary Lee Bowden in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Sociology.

Richard Wanner

Chairman,
Dr. Richard Wanner,
Department of Sociology

Scott Long

Dr. J. Scott Long,
Department of Sociology,
Washington State University

A. Brannigan

Dr. Augustine Brannigan,
Department of Sociology

Donald L Mills

Dr. Donald Mills,
Department of Sociology

James McRobinson

Dr. James Robinson,
Faculty of Management

Date: May 9, 1984

ABSTRACT

Current understanding of epistomology suggests the utility of a sociological approach to the production of scientific knowledge. Current research in this area falls into two theoretical camps, interest theory and attribution theory, based upon the the conception of knowledge utilized, the location of causality in the theoretical model, and the analytic primacy accorded "how" and "why" questions. The relative explanatory utility of these two accounts is examined through an analysis of the history of U.S. crude oil resource estimates.

Estimates of ultimately recoverable, conventional U.S. crude oil resources, when compared, yield a distinct historical pattern definable on the basis of three criteria: 1) the mean magnitude of the estimates produced within a chronological period, 2) the amount of variation around that mean, and 3) the timing of the breaks between periods.

It is shown that two distinct types of social phenomena are largely responsible for this pattern. Changes in the political economic environment of the international oil industry are responsible for both the changes in the mean magnitude of the estimates through time

and the existence of discrete periods. The amount of variation around the mean of the estimates in a given period, however, stems from organizationally based differences in the magnitude of the estimates produced and the interaction of organizational factors with changes in the magnitude of proven reserves. These findings, while not necessarily antithetical to the attributionalist account, clearly harmonize with the interest model of explanation.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the following individuals for the time and effort they have expended upon his behalf: Dick Wanner, Gus Brannigan, and Jim Robinson for their willingness to read and comment upon repeated drafts of the manuscript; Tom Huang for preparing the computer graphics; and the Department of Sociology for its financial support of this and other academic endeavors of mine. In addition, the author would like to express his gratitude to the individuals interviewed in the process of preparing this thesis. Most of all, I am grateful to Peggy Wight, she provides an an unlimited resource of oil to lubricate my daily life.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

ORGANIZATIONAL CONTEXT AND THE PRODUCTION OF SCIENTIFIC KNOWLEDGE

Sociological studies of science can be divided into two major traditions. On one hand are normative studies of science as an institution. On the other are studies in the sociology of scientific knowledge.(1) The former include studies of the institutional origins of science (e.g. Merton, 1938), the reward system of science (e.g. Merton, 1957) and the organization of science both formal (e.g. Kaplan, 1965) and informal (e.g. Crane, 1972). In general, these studies bring a unified theoretical perspective, that of functionalism, to bear upon sociologically relevant aspects of science as an institutional structure but avoid subjecting the production of scientific knowledge to sociological scrutiny.

Studies in the sociology of scientific knowledge, on the other hand, are unified by their subject of study (i.e.

---

(1) Mulkay (1981) provides a thorough and recent survey of both traditions. Ben-David and Sullivan (1975) provides a thorough albeit dated summary of research in the sociology of science. Collins (1983) reviews studies of contemporary science from the perspective of the sociology of scientific knowledge. Shapin (1982) provides exhaustive review of the historical studies which contribute to that perspective.

the production of scientific knowledge) and a common theoretical heritage (i.e. those notions common to all "interpretive sociologies", e.g. orientation to the actors perspective and reference to a linguistic or conversational order as the practical medium whereby meaningful action is organized reflexively by human agents) but share little agreement about what counts as "valid" explanation. While agreeing that the direct contemplation of nature does not in and of itself generate knowledge of the natural world and that, hence, scientific knowledge, like other human products, must be viewed as a social construction, a plethora of theoretical/methodological prescriptions have been offered. Among the approaches presently being advanced are ethnographic studies of laboratory settings (e.g. Latour and Woolgar, 1979; Knorr, 1981), discourse analysis (Mulkay and Gilbert, 1982a; 1982b), interest explanations (Shapin, 1979; 1982; MacKenzie, 1981), conflict theoretical studies of mathematics (Collins and Restivo, 1983) and attributional theories of scientific discovery (Brannigan, 1981).

In addition to the theoretical and substantive demarcations between the two traditions, a methodological demarcation has also arisen. While both camps embrace historical analysis, normative studies of science have traditionally utilized quantitative techniques (e.g.

statistical analysis of reward structures, citation and network analyses of research specialties) to analyze data from surveys or secondary sources (e.g. citation indexes, dissertation abstracts, or the membership lists of organizations). Constructivist studies, however, have relied almost exclusively upon qualitative methods and case studies. Although these methodological differences are overwhelmingly evident, they are arguably not essential.(1)

Through an analysis of the relationship between organizational context and the production of natural resource estimates, this thesis illustrates how statistical techniques can be used to amplify constructivist sociology of scientific knowledge. In several ways, the following analysis is merely an elaboration of earlier constructivist approaches. Pinch (1982), for example, analyzed the changes in neutrino-flux predictions made by a particular theorist through time, explaining the direction and timing of changes in the numerical predictions through reference to aspects of the social context relevant to the funding of experiments. Analogously, the following analysis of U.S. crude oil resource estimates also looks at changes in the numerical value of theoretical predictions made at

---

(1) The exceptions to this are, of course, certain modern theoretical views that are explicitly tied to a particular methodological technique (e.g. discourse analysis, ethnographic description, etc.).

different times. By examining the population of predictions made through time, rather than merely those of a particular individual, one can contrast not only the direction, magnitude and timing of changes made by different individuals, but can also contrast the patterns in terms of characteristics of either the estimate (e.g. estimation methodology) or the estimator (e.g. estimator's employing organization). In addition, one can analyze changes in the variation among the predictions through time, a dimension totally absent from Pinch's case study analysis. In short, statistical techniques can be used to recover and display information unavailable through other research strategies and this information can be understood and explained through reference to theoretical models developed within the interpretivist framework.

Estimates of the crude oil resources of the United States provide a viable locus for such an analysis. First, the use of statistical techniques requires a sizable number of cases. Approximately 100 of these estimates have been produced since 1940. Although not extremely large, this is an acceptable number (particularly since it represents the population and not a sample). Second, characteristics of the estimators and estimates must vary; one cannot explain variation among predictions through reference to constants. Estimates of U.S. crude oil resources have been produced by a variety of individuals trained in a variety of disciplines utilizing a variety of estimation methodologies and employed by a variety of organizational types. Third, the estimates have been at the heart of several controversies. Thus, it is possible to examine the relationship between the emergence (or disappearance) of controversy and changes in the aggregate pattern of estimates across time. Fourth, the estimates were recently produced. Thus, it is possible to supplement the statistical analysis with material gained from other sources (e.g. interviews and historical documents).

The selection of crude oil estimates as the locus for such a study is not without a number of limitations. Most importantly, access to the raw data utilized in the production of the estimates is, in many cases, severely constrained. Oil companies spend massive amounts of money collecting such information and, since it forms the basis of their exploration decisions, guard it jealously. Thus, in most cases one cannot describe precisely how a particular estimate was established. As a result, even case study analysis would not allow one to fully reconstruct the range of interpretive flexibility embedded within most particular estimates. Second, the estimates, as published, do not always refer to the same conceptual entity. Thus, to avoid comparing apples with oranges, adjustments must be made to some of the estimates. It would have been preferable if the estimators had produced estimates that were comparable without adjustment.

Since the government and the oil industry both produce these estimates and utilize them in making policy choices, natural resource estimates provide a strategic research site for examining the relationship between organizational context and the production of scientific knowledge. A number of earlier studies within the sociology of science and the sociology of scientific knowledge relate directly to this question. Early studies of scientific work within differing organizational settings adopted the normative perspective and attempted to specify the optimal organization of research work. Peltz and Andrews (1966), for example, examined the relationship between individual autonomy and coordination of the laboratory group. In essence, they found that in loosely coordinated laboratories (e.g. universities, Bell Laboratories) high individual motivation was necessary for achievement while highly autonomous scientists performed best in middle-range coordination settings. Another set of studies (e.g. Weinberg, 1967; Swatez, 1970) suggested that the organization of research work differs among university, government and industry laboratories because they engage in different types of work; research institutes and industry laboratories involve large scale work requiring greater coordination. Normative studies of research teams have also focused upon organizationally based differences in patterns of communication (Allen, 1966), the relationship between productivity and such patterns of communication (Allen and Cohen, 1969), and the effect of organization upon job satisfaction (Parsons and Platt, 1973). The rationale behind this entire corpus of work envisions a functional system in which various organizational and career structures are differentially related to productivity and innovation. Thus, the proper organizational/career environment facilitates productivity and innovation but does not impact upon the actual content of the knowledge produced.

Several recent studies, however, have either documented or hinted at the existence of organizationally based differences in the production of scientific knowledge. Several such studies are found in the volume edited by Irvine, Miles and Evans (1979). Specifically, these articles document how government statistics act as "mystifying" devices that legitimate the interests of the capitalist class. These studies suffer, however, from their failure to compare the production of similar types of statistics in different types of organization. Thus, while they claim to document the relationship between organizational interests and the statistical products produced within these organizations, these studies do not demonstrate that organizations with differing interests actually produce different statistical claims. Peach (1982), drawing upon many of the same intellectual sources albeit in a less polemical manner, provides a number of case studies taken from a variety of organizational types (e.g. government, industry, public interest group, and private foundation) that illustrate the tension and interpenetration of professional and organizational interests in the production of applied statistics. Like the studies in Irvine, Miles, and Evans (1979), Peach explains a process that may lead to the differential production of scientific knowledge within differing types of organization but does not demonstrate that such a result actually obtains.

Lynn (1983), on the other hand, demonstrates the existence of significant differences between industry, government, and academically employed scientists and their attitudes toward acceptable levels of environmental risk but does little to explicate the process that generates such differences. She, like Mazur (1981), Conrad (1982) and other analysts of technical controversy, suggests that differing knowledge claims arise from differences over interpretation rather than differences over facts.

According to these authors the basis to technical controversy can be found in the different ways that the protagonists link scientific knowledge to other already existing cognitive structures (e.g. world views) and the correspondingly different modes of using this knowledge. Thus, these authors treat controversy as the result of a process that links "facts" to policy choices through the adoption of a particular theoretical interpretation.

In a number of technical controversies, generally involving potential governmental regulation of lucrative commercial enterprises, direct contention over data has occurred.(1) In the case of saccharin, for example, neither the government nor the industry trusted the other to conduct "unbiased" research (Priebe and Kauffman, 1980). The suggestion in these cases is that the parties engaged in funding the research have either economic or political interests in particular results and fund researchers who will document their desired case. Generally, there exists a perception that the protagonists have everything to gain and nothing to loose if their case prevails and, hence, biasing the data has no negative effects. Although a number of popular accounts suggest that industry estimates

(1) Schultz (1979) provides an interesting account of how governments and foundations have biased the content of economic research.

of crude oil resources are essentially propaganda (see, for example, Sherrill, 1974), this position is logically contradictory with the fact that the industry frequently utilizes these estimates, albeit in a less aggregated form, for exploration decisions involving millions of dollars of their own money. It is highly unlikely that the industry would base such decisions upon estimates they know to be consciously manipulated or to involve data that has been "fudged". Thus, if organizationally based differences exist, they cannot be treated as suggesting that the estimators are operating in bad faith or manipulating the data.

Robert Anderson, through a series of case studies (Anderson, 1967; 1975), has illustrated the crucial role of research institutions as an intervening variable between individual scientists, their groups and specialties, and national policies on one hand, and the social and cultural conditions which influence them on the other. While Anderson advocates a particular type or organization (the research institute) as the best location for such studies, his approach is clearly comparative and he openly acknowledges the utility of comparing the findings from studies of research institutes with findings from studies undertaken in the less "autonomous" settings of government, industry, and academia. Thus, Anderson's research provides a mechanism for explicating the existence of organizationally based differences in scientific results without calling into question the motivations of the practitioners.(1) As Anderson (1981:213) notes, the focus is upon "the sequence of questions to be asked about the relationship of internal and external influences within the research institution. The questions locate the research institution as the mediator between 'the scientific tradition' and individual researchers' contribution to it, and national policies and socio-cultural traditions."

In sum, there exists a small but growing literature either documenting or suggesting the existence of organizationally based differences in the production of scientific knowledge. This literature, however, generally raises more questions than it resolves. How are these differences generated? Are they merely differences in interpretation or do they include differences over facts as well? Why do these differences occur? Are they the result of differential training or recruitment? Does the

---

(1) It would be naive, given the massive amounts of money involved, to assume that estimators never consciously influence the estimation process in order to achieve results justifying government or industry policy. It would be equally as naive, however, to suppose that such manipulation occurs in every case. The position adopted here is an essentially conservative one; any acceptable explanation of the variation in estimates must account for the fact that the majority of the estimates are made in good faith.

organization provide a particular culture that leads to differing perceptions? What is the role of the organization? Does it act as a passive carrier of established scientific practice? As a location for the active creation of acceptable scientific practice? As a mediating variable? These substantive questions form the heart of the following thesis.

The following chapters will document the fact that estimates of ultimately recoverable conventional crude oil for the United States have varied as a function of organizational type, i.e. there exist differences among the theoretical predictions made by industry, government, and "independent" estimators. This thesis attempts to explain why these differences exist through reference to theoretical models developed in other studies of scientific practice.

Chapter 2 examines the two major forms of explanatory account presently utilized within the sociology of scientific knowledge; internalist accounts of how knowledge is produced and externalist accounts of why members of a given social grouping produce similar knowledge claims. Statistical techniques, properly utilized, can facilitate an understanding of the relationship between these two forms of account by encompassing both internal characteristics of scientific practice (e.g. estimation methodology) and external characteristics of the social context (e.g. the estimator's employing organization).

Chapter 3 demonstrates the existence of a pattern among the estimates of ultimately recoverable U.S. crude oil resources. This overall pattern consists of a number of chronologically distinct periods specifiable in terms of the mean magnitude of the estimates produced during the period, the variation among the estimates produced during the period, and the timing of the breaks between periods. A number of plausible explanations for the pattern are examined.

Chapters 4 and 5 examine the three charactersitics associated with the aggregate pattern. Chapter 4 analyzes the change in the mean magnitude of the estimates through time. It is shown that the chronological change in the mean magnitude of unknown resources reflect chronological changes in quantities that are known with much more assurance (e.g. the magnitude of past production and proven reserves). This suggests that estimators base their theoretical predictions about the magnitude of unknown resources upon an interpretation of "current experience". Chapter 4 also examines chronological change in the variability among estimates produced at approximately the same time. It is shown that both internal and external aspects of the situation have a significant impact upon the magnitude of the estimate produced and, hence, the variability among estimates. Examination of the relationship between the various internal and external features suggests that organizational context impacts upon the researcher's practice of science. Chapter 5 turns to an analysis of the political economy of the international oil industry in order to forge a relationship between changes in that context and the timing of the breaks between periods.

Chapter 6 examines estimates of world and Canadian crude oil resources in an attempt to both elaborate upon and further demonstrate the utility of the explanatory account offered in the previous chapters.

Chapter 7 summarizes the main themes of the substantive analysis and draws out their implications.

CHAPTER 2

THE SOCIAL BASIS OF U.S. CRUDE OIL ESTIMATES

The previous chapter drew a distinction between the sociology of science and the sociology of scientific knowledge. The former holds that society impacts upon science as an institution but not upon the production of scientific knowledge while the latter holds that society impacts upon both science as an institution and the production of scientific knowledge. Thus, the explanation of resource estimates given within these two traditions would be markedly different. Sociologists of science, like scientists themselves, have given naturalistic explanations of scientific knowledge; they hold that science has a privileged epistomological status and that proper adherence to the methodological strictures of science necessarily reveals the truth about nature. Alternatively, sociologists of scientific knowledge have given sociological explanations of scientific knowledge; they hold that science does not possess a privileged epistomological status and that the production of scientific knowledge, like the production of other forms of belief, is a thoroughly social process.(1)

Proponents of the constructivist position hold that scientific knowledge is socially based. This view draws upon a broadly phenomenological approach which holds that <u>all</u> phenomena associated with scientific research are socially constituted and recognized. This research does not focus upon how extra-scientific forces lead scientists astray but, rather, examines the process whereby scientists constitute knowledge as "scientific". Thus, the constructivist position does not result in a "sociology of error" in which the ability to provide a sociological account of a knowledge claim stands as a critique of its scientific status, i.e. social influence makes science go awry. Scientists and sociologists of science alike have traditionally assumed that there is no need to explain "true" beliefs. Only if the belief is "false" need we search for a cause explaining its adoption. The symmetry thesis, a central postulate in the sociology of scientific knowledge, holds that all scientific claims, irrespective

---

(1) For an examination of the positions adopted by individuals within both traditions toward the epistomological status of science, see Mulkay (1979). For an elaboration of the distinction between naturalistic and sociological explanations, see Brannigan (1980).

of their truth or falsity, are subject to sociological scrutiny.(1)

THE FORM OF EXPLANATORY ACCOUNT

Beyond this initial point of consensus, however, the constructivist position displays a considerable diversity. The fundamental point of contention hinges upon the proper form of explanatory account. The various factions can, with a certain amount of ambiguity, be grouped into two basic categories -- attributional theorists and interest theorists -- based upon their definition of an explanation, the location of the ultimate causal variable in their theoretical models and the type of question to which they give explanatory priority. Attribution theorists (e.g. Brannigan, Collins, Lynch, Mulkay, Woolgar, Knorr) adopt a (broadly conceptualized) phenomenological orientation, locate cause within the actor's practice of science itself and attempt to explain how knowledge is produced. Interest theorists (e.g. Barnes, Pickering, Shapin, MacKenzie, Travis) adopt an instrumental orientation, locate cause outside the realm considered scientific by the actor and

---

(1) See Brannigan (1981:63) for an analogous view of the social basis of discovery. See Barnes (1974) or Bloor (1976) for an elaboration of the symmetry thesis.

attempt to explain why a community of individuals share belief in specific knowledge claims.(1)

Attribution Theory

Although there exist a variety of substantive and methodological differences within the attributionalist camp, e.g. laboratory studies (Latour and Woolgar, 1979; Lynch, 1979; Knorr, 1981), discourse studies (Mulkay and Gilbert, 1982a; 1982b), core-set studies (Collins, 1975; 1981c), and models of the discovery process (Brannigan, 1981), these differences are more a function of individual orientation and the methodological necessities for addressing particular questions than they are a reflection of fundamental theoretical differences. All of the above theorists treat linguistic codes and discursive practices as the medium through which scientific knowledge is produced and draw upon the theoretical concepts of phenomenology and ethnomethodology to explain how this

---

(1) Both groups treat the boundary drawn between science and non-science by the historical actor as the relevant demarcation of what is "scientific". This position differs markedly from that adopted by a number of philosophers and historians of science in which the analyst makes a normative prejudgment about what counts as "science" and what does not and imposes that judgment upon the historical actors. This should not be taken, however, to suggest that the boundary between science and non-science within a historical context is always clearly delineated.

takes place. The apparent diversity among these approaches largely results from the difference between an orientation toward depth of knowledge about a specific topic versus an orientation toward scope of knowledge about an overall process that has been exaggerated as a function of academic product differentiation.

Attributional theories are held together by their common concern for how a piece of knowledge comes to be constituted as scientific fact. These models treat validity, discovery, priority, replication and other aspects of scientific practice as objectified social statuses conferred by members upon particular claims or accomplishments. The focus is not with what makes something (e.g. a discovery) occur, but, rather, with how it was identified by members as possessing that status. Following the lead of post-Wittgensteinian philosophy, attribution theorists hold that the process of learning a language provides an individual with means for structuring the world by defining the way in which things are grouped into linguistic categories, the manner in which these groupings are perceived to be connected and the common sense criteria that structure their recognition (see Brannigan, 1981:64-70). Thus, attribution theory draws upon the common sense grounds utilized by members to account for differences in scientific results and, hence, would account for the differences among resource estimates in terms of differences in method, assumptions, data or other features internal to the practice of science.

Latour and Woolgar (1979) provide a nice illustration of the attributional approach; they argue that the creation of scientific "facts" is the outcome of scientists discursive practices. "Facticity", i.e. the extent to which a given knowledge claim has been given an objectified status within linguistic discourse, changes as scientific practice undertakes operations designed to result in the dropping of those linguistic modalities which qualify a given statement. As a result, Latour and Woolgar treat "reality" as the consequence rather than the cause of a particular construction and view scientific activity as directed toward the transformation of discursive statements rather than toward "nature". In short, Latour and Woolgar embed science within local circumstance; scientific facts are not just surrounded or influenced by, partially dependent upon, or also caused by circumstance, they are fabricated out of circumstance (see, especially, page 239).

The prominence accorded local circumstance by Latour and Woolgar points to the largest actual difference among attribution theorists; the methodological locus of the study. Collins (1981c), for example, advocates the analysis of competing claims among a "core-set" or community of researchers while the advocates of laboratory studies favor the local context. As Brannigan (1981:87) persuasively argues, anthropological studies of laboratory settings run the risk of "ethnographic dazzle", i.e. losing sight of what all the details are details of. Indeed, the strength of Brannigan's analysis of scientific discovery lies in its putting aside the extreme focus on local circumstance in order to provide an explanation (rather than a description) of how something comes to be constituted as a discovery. He does this by outlining the necessary and sufficient conditions for this to occur. According to Brannigan, the status of an event as a discovery is a function of the perception of the community and the scientists themselves that "the events of the research were possible, motivated achievements which were substantively true or valid and whose announcements were unprecedented." Since these conditions are also meaningfully adequate for the actors, Brannigan maintains an internalist perspective. Thus, Brannigan provides an explicit example of an <u>explanation</u> of how an event becomes constituted.

As noted above, attribution theory explains the differences in scientific results through reference to concepts internal to members understanding of scientific practice. Thus, while admitting that external social conditions can impact upon science(1) they maintain that such occurrences, as perceived and reported by the historical actors, are extremely rare. Accordingly, they claim that to focus upon the role of external factors is to suggest that the creation of scientific facts only occasionally or partially exhibits the influence of sociological features. Attribution theory holds instead that the production of scientific facts is always and everywhere a thoroughly social process. Interest theorists, like attribution theorists, view science as a thoroughly social process. Unlike attribution theory, however, interest theory traces the differences in scientific results to factors external to the practice of science (e.g. characteristics of the scientists).

Interest Theory

Interest explanations focus upon the question of <u>why</u> communities of individuals impute validity to the same knowledge claims and why those shared imputations change

---

(1) See, for example, Latour and Woolgar's treatment of the role of ideology (Latour and Woolgar, 1979:123), career determination (Latour and Woolgar, 1979:119), and institutional factors (Latour and Woolgar, 1979:139).

through time.(1) This approach, having developed out of early programmatic statements (e.g. Barnes, 1974; 1977; Bloor, 1976), shows a considerable amount of theoretical unity in its application. The work of MacKenzie (1981), which has been repeatedly cited as the paradigmatic example of this type of analysis, takes the following form: Differing scientific views are attributed to two or more specific actors. The actors are shown to have differing social affiliations (most frequently social class). Documentary evidence is introduced to display that one or more of the protagonists actively supported political actions on behalf of their class interests and it is suggested that the actors' scientific views, irrespective of whether or not they ultimately prevailed, promoted their class based objectives. Thus, it is argued that the scientific thought of particular individuals took the specific content that it did because science was used as a resource for promotion of their political interests. In sum, an external cause (e.g. social class affiliation)

---

(1) See Barnes (1981) for an elucidation of the rationale that treats "why" questions as fundamental. See Woolgar (1981b:509-11) for an attributionalist denial of the fundamental nature of "why" questions.

acts as the ultimate source of causation in the theoretical model.(1)

In justifying this type of explanation, interest theorists draw heavily upon many of the same traditions as the individuals that figure prominently in the sociology of science (e.g. Mannheim, Merton) and augment this with strands drawn from both ethnomethodology (e.g. Garfinkel) and critical Marxism (e.g. Habermas). Interest theorists, like those in the attributional school, follow the linguistic turn in sociology associated with post-Wittgensteinian philosophy. Both groups dismiss the "reflective" view of the world (i.e. that linguistic accounts are a straightforward re-presentation of the world). They differ, however, in the extent to which they treat ethnomethodological concerns as central to the form of explanation. Interests theorists, on the one hand,

---

(1) Although MacKenzie's work is generally cited as the exemplar of this type of analysis, Shapin's (1975; 1979) papers on phrenology in 19th century Edinburgh actually provide a better illustration. Not only is the connection between social class and belief more convincingly documented, but Shapin's work is non-evaluative. Placing MacKenzie's work in the context of his other writings (especially MacKenzie, 1981b), lends credence to a reading of his work as an attempt to display certain scientific beliefs as wrong because they are expressions of a capitalist system. Shapin's work lacks this evaluative dimension and, hence, cannot be read as reducing to a "sociology of error" which, on the face of it, appears incompatible with the symmetry thesis.

adopt a "mediative" view that accounts are the products both of reality and the complex of social, cultural and historical circumstance that intervenes between reality and the account that is produced. Attribution theorists, on the other, hold that accounts are "constitutive" of reality.(1)

According to interest theory, if knowledge cannot be gained through passive contemplation then any differences between two systems of natural knowledge must be attributable to variation in the criteria or principles of selection which reflect the active participation of the actors in the process of creating the knowledge. Following Habermas (1972), they hold that such criteria can always be viewed as responding to a need or interest. Thus, interests form a "necessary contingency"; without them there would be no way of sorting the world.

Attribute versus Interest

The precise relationship between these two forms of explanatory account is presently the topic of lively debate. A number of the internalists (e.g. Woolgar, 1981; Mulkay and Gilbert, 1982c; Yearley, 1982) view externalist

---

(1) See Woolgar (1981b:507) for an elaboration of the "reflective", "mediative", and "constitutive" views.

accounts as antithetical to their program while others (e.g. Collins, 1981a; 1983) have expressly advocated externalist approaches as an extension of their program. The views of the various attribution theorists on this matter are closely related to the methodological focus of their studies and the substantive definition of knowledge that results. Most attribution theorists pay strict attention to the constitution of knowledge within a localized laboratory setting and, hence, their work sheds relatively little light upon the notion of knowledge as valid within a community of scientific practitioners. Lynch (1979), for example, gives no indication that the knowledge claim for which he documents the localized constitution of validity was only one competing claim within a larger controversy among members of a larger research community. Collins, like the interest theorists, considers knowledge not in terms of its local interpretation but, rather, in terms of its relation to a general consensus within a network of quasi-independent individuals. Thus, for Collins, the question of why individuals within the network share particular views carries considerably more impact than it does for individuals studying a local laboratory setting.

The differences between the attribution and the interest theories, however, is more than methodological; it centers upon the ultimate location of causality in the explanation of the phenomenon under study. Attribution theory accounts for the production of a particular knowledge claim in terms of factors internal to the practice of science. Thus, in the case of resource estimation, attribution theory would explain differences in the magnitudes of various estimates through reference to the characteristics of the estimate (e.g. methodology, data base, etc.). Alternatively, interest theory accounts for the production of particular knowledge claims in terms of factors external to the practice of science (i.e. the interests of the scientist). Thus, in the case of resource estimation, interest theory would explain differences in the magnitude of various estimates through reference to the characteristics of the estimator (e.g. social class, organization of employment, etc.).

INDEPENDENT AND DEPENDENT VARIABLES

The following chapters attempt to explain the social basis of variation among estimates of undiscovered U.S. crude oil resources. In order to accomplish this the numerical value of the estimate will be treated as the dependent variable. Adopting the individual estimate as the unit of analysis facilitates an examination of the effects of characteristics of both the estimate (e.g.

method) and the estimator (e.g. employing organization) upon the dependent variable. In addition, it allows for the use of both internal and external independent variables and, hence, an examination of the relative applicability of the two forms of explanatory account outlined above.

The major independent variables to be examined are time, method of estimation, disciplinary training, economic assumptions and organizational affiliation. These variables were chosen for three basic reasons. First, they represent plausible explanatory variables; differences over acceptable methodological practice or economic assumptions are frequently cited by estimators as underlying differences in their results (see, for example, Ryan, 1965; Hubbert, 1965; Netschert, 1958:7-24), while, in other settings, both disciplinary or occupational training and organization of employment have been shown to be predetermined variables which affect the production of knowledge claims (Robbins and Johnston, 1976; Irving, Miles and Evans, 1979). Second, these variables include both internal and external characteristics; methodology and economic assumptions are clearly internal to the practice of science while organization of employment is clearly external. Disciplinary training/occupation falls midway between, it is neither clearly internal nor clearly external. Third, values for these variables can be gained in most cases. Given the relatively small number of cases, it is necessary to select variables for which there will be few missing values.

Magnitude of the Estimate

The dependent variable, magnitude of the estimate, was operationalized by the numerical value of the estimate as expressed in billions of barrels of crude oil (where 1 barrel = 42 U.S. gallons). When the estimate was expressed as either a range or a probability distribution and the estimator gave no indication of a preferred central value, then either the mean of the range or the 50% probability value was utilized as the central value for the purpose of computing a point value for the estimate.

In the course of this thesis, reference will be made to a number of conceptually distinct types of estimates. Figure 2.1, modified from McKelvey (1975), illustrates the conceptual categories that will be used to differentiate between various types of estimates. The term "resource base" refers to the total amount of oil existing in a given geographical area in commonly recognizable form. "Past production" refers to that amount of oil which has actually been removed from the ground as of a specific date. "Proven reserves" refer to the amount of oil in the ground that, with reasonable certainty, could be produced in the future under current economic and operational conditions from deposits established on known geological and engineering data. "Unknown resources" consist of that portion of the resource base exploitable under existing economic and technological conditions but located either in unproven extentions to known pools (inferred reserves) or in pools that have not yet been discovered (undiscovered resources). "Marginal resources" consist of that portion of the resource base, both discovered and undiscovered, that is not exploitable under present conditions of economics and technology but which would become exploitable with forseeable changes in those conditions. "Submarginal resources" consist of that portion of the resource base that cannot be exploited for the use of man irrespective of changes in the economics and technology of extraction. Several other useful terms can be defined through reference to these categories:

Remaining recoverable resources = Proved reserves + Unknown resources + (potentially) Marginal resources

Ultimately recoverable resources = Remaining recoverable resources + Past production

Estimates of remaining resources are time bound in that they represent estimates as of a specific date (e.g. 1957 or 1980) and, everything else being equal, will differ by the amount of production that occurred in the intervening years. Estimates of ultimately recoverable resources avoid this problem through the inclusion of past production; they are estimates of remaining recoverable resources adjusted to a common point of perspective -- the beginning of production records in the 1860's.

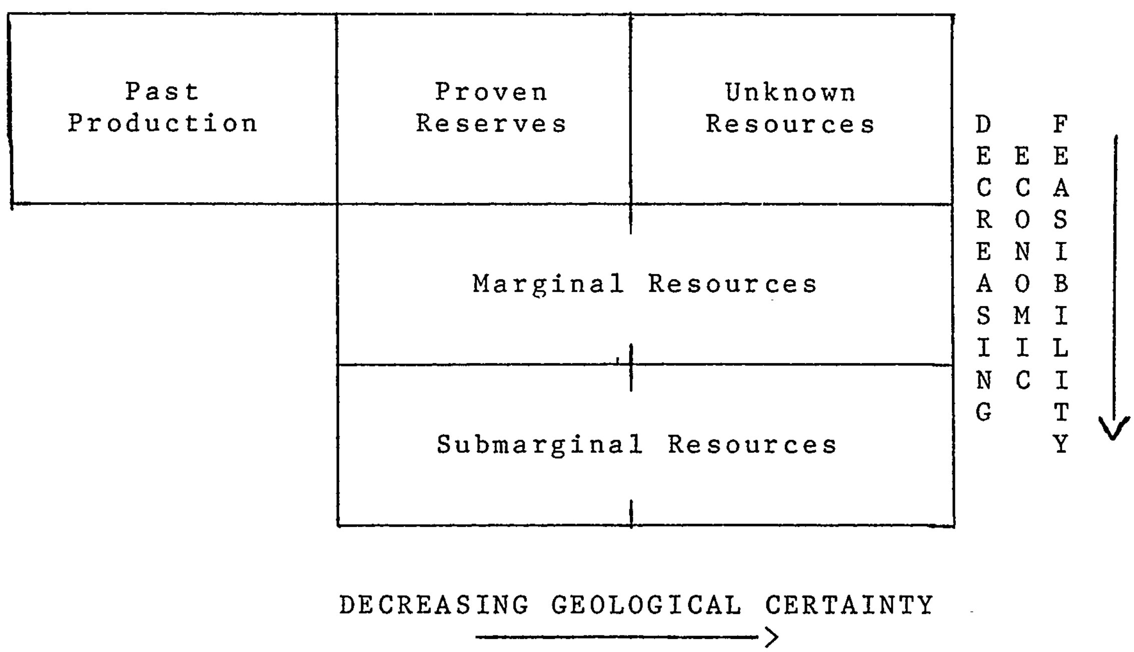


FIGURE 2.1:CONCEPTUAL RELATIONS AMONG GEOLOGICAL TERMS (ADAPTED FROM MCKELVEY, 1975).

Time

Time, one of the independent variables, was operationalized as the year in which the estimate was first made public. Thus, it refers to either the date of publication or, in the case of estimates that were not published, to the date the estimate was presented at a meeting. In the case of estimates that were published repeatedly with little or no modification, only the first instance has been included. In the case of estimates that were presented at meetings prior to publication, reference has been made to the published version since preprint versions are less available and occasionally contain errors.

Although time plays a prominent role in many of the statistical models developed in this thesis, these models are technically misspecified. Time, a contentless variable, does not in and of itself explain anything. Thus, in those models that utilize time as an independent variable it is acting as a surrogate for other things, particularly the "period" effects induced by historical events. Models developed later in the thesis remove time from this surrogate role by specifying the variables that are responsible for the "time" effect.

Methods of Estimating Resources

There exist a variety of methods which can be used to estimate the availability of oil and gas resources. These methods and the various situations to which they can be applied are shown in Table 2.1.

METHOD	VARIATIONS APPLICABLE TO:			
	PROSPECT	PLAY	BASIN	COUNTRY
Geologic Analogy	X	X	X	X
Areal Yield	X	X	X	X
Volumetric Yield	X	X	X	X
Geochemical Material Balance	X	X	X	X
Field Number and Size		X	X	X
Extrapolation of Discovery Rate			X	X

TABLE 2.1: QUANTITATIVE METHODS OF ASSESSING POTENTIAL VOLUMES OF UNDISCOVERED HYDROCARBONS (ADAPTED FROM WHITE AND GEHMAN, 1979).

Although estimates of specific prospects or plays can be aggregated to arrive at an estimate for a larger area, there exist a number of estimation methodologies (e.g.

extrapolated discovery rate) which cannot be disaggregated to yield estimates for a specific prospect or play.(1)

For the purpose of this thesis, methods have been categorized as one of the five following types: geological analogy, volumetric yield, field size, exploitation history, or other.(2) Unfortunately, the number of estimates that have been produced using either the "field size" or "other" methods are relatively small. Thus, although separated for the purpose of identification in Table 2.2, the field-size estimates have been collapsed into the "other" category for the purpose of the statistical analysis.

---

(1) "Prospect" refers to an area that is a potential site of oil or gas based upon preliminary exploration. "Play" refers to the extent of a particular petroleum bearing formation and, hence, may include a number of distinct prospects. "Basin" refers to the geological form of an area as defined by the structural arangement of its rocks and, hence, may include a number of distinct plays.

(2) This section provides only a brief overview of the various methodologies. For a more elaborate treatment of the subject consult White and Gehman (1979) or Schanz (1978). The geological material balance method, used primarily in the U.S.S.R., has not been covered here. It should also be noted that the following synopsis treats the methods generically. There is a tremendous variation in the application of each of these types and, hence, a precise understanding of the methodology and assumptions utilized to arrive at a particular estimate must be gained from the original source.

The above classification has been adopted because it includes the major methodologies identified by authors who have reviewed the field of resource estimation (e.g. White and Gehman, 1979; Schanz, 1978) but avoids drawing detailed distinctions between techniques that share an underlying methodological similarity as frequently occurs in specialist reviews of a particular methodology (e.g. Wiorkowski, 1981). The brief descriptions that follow are provided both to document the criteria utilized in classifying methodologies and to illustrate the kinds of interpretive flexibility associated with each of the methods.

1) Geological Analogy

The earliest method for estimating undiscovered resources, assessment by geologic analogy, operates on the principle that if untested area A appears geologically similar to known producing area B, then it will have a similar oil and gas content. In practice, this method is supplemented with a scaling factor taken from one of the other methods in order to compensate for obvious differences between the areas (e.g. sedimentary volume). Some geologic analogies are based upon comparison of single key geologic controls of hydrocarbon occurrence (e.g.

source beds, reservoir beds or trap enclosures). Most of the analogies used to evaluate large areas, like those examined in this thesis, are based upon a broader comparison of genetic basin types.

Several important facts should be noted about the analogic method. First, the geology of petroleum occurrence is highly complex and not extremely well understood. As a result, the selection of a criterion feature or features as the basis for establishing "geologic similarity" can become quite arbitrary. Indeed, in many cases, the perceived similarity between basins arises from the previous experience of the estimating geologist; the geologist perceives as primary some aspect of the unknown basin that is similar to the basin he or she knows best (Hea, 1981). The MacKenzie Delta/Beaufort Sea area provides a nice example. Imperial Oil, whose geologists have experience in the North Sea oil fields, use that area as a comparative basin since both areas are offshore. Dome Petroleum, however, bases its estimates for the same region on a comparison with the Kara Basin of the Soviet Union because both areas possess shale diapirs.(1) Second, the analogies are based upon an inferred geologic structure

---

(1) Diapirs refer to arch-shaped folds in stratified rocks in which the underlying rock (in this case shale) has pierced upwards through the vault of the arch.

which is subject to revision. For example, the diapir structures upon which Dome bases its estimates were originally identified as salt domes.(1) Third, there is a strong argument that the success or failure of the method depends less on the similarities and more on the differences that exist between the areas being compared (White and Gehman, 1979).

2) Areal and Volumetric Yield

A second major kind of estimation technique, those based upon the calculation of yields, can be subdivided into two basic types: areal and volumetric. In essence, the areal method arrives at an estimate by multiplying the area of a basin times the percentage of that area expected to be productive. This quantity is then multiplied by an estimate of the number of barrels that will be found per productive acre (or other standard unit of area) in order to arrive at an estimate of recoverable resources. Since this method does not take into account variation in the third dimension, depth, it has largely been replaced by the volumetric method.

---

(1) A salt dome is the structure that results when a salt plug forces its way upward through a series of sedimentary strata, partly breaking through them and partly pushing and bending them upward.

The volumetric approach to basin assessment usually involves multiplying basin area times total sediment thickness times a yield in barrels per cubic mile (or other standard unit of volume). Common variations involve calculating the volume of reservoir facies only, or the volume of source facies only, together with a modified yield factor.(1)

Yield estimates, perhaps more than any other type, have been criticized for their arbitrary nature (Hedberg, 1975; Hubbert, 1962:44). As Klemme (1976) has pointed out, yields for explored basins range from 0 to 4 million barrels per cubic mile. Despite the obvious effects that selection of a particular yield factor has upon the magnitude of the estimate, there is no established method for deciding what the average return of a basin or play will be before it is drilled. Thus, the selection of the yield factor is left largely to the discretion of the estimator. It should also be noted that the interpretation of geologic maps changes with shifts in geological theory (Harrison, 1963) and that the use of different types of

---

(1) The term "facies" is used to capture all characters of a sedimentary unit, organic and inorganic. Thus, calculations may be based upon the volume of source rocks (i.e. the rock in which petroleum is formed and from which it migrates) or the volume of reservoir rocks (i.e. the rocks capable of containing and storing oil and gas).

maps can lead to considerable variation in the measurement of sediment thickness (Pennebaker, 1972).

3) Field Number and Size

A third major method of resource estimation involves the use of field number and size in play assessment. This method begins with an assessment of the number of prospects in an area (e.g. the number of stratigraphic traps) which, when multiplied by an assumed success ratio, estimates the number of potential fields. This number is then multiplied by the average field size in order to arrive at an estimate of the hydrocarbon resource in the play. The Canadian government (Roy, Procter and McCrossan, 1975; Energy, Mines and Resources, 1977) currently use a sophisticated version of this technique. Rather than deriving a numerical average for the parameters of field size and potential prospects, they utilize distributions which are entered into a Monte Carlo simulation. The result ia a probability curve.

The major disadvantage of this method is the tremendous amount of seismic information needed in order to define most of the prospects. Thus, the method is particularly difficult to apply in areas that are relatively unexplored and the prospects such as stratigraphic traps, are not easily defined.(1)

4) Exploitation History

The fourth major estimation methodology, extrapolation of historical discovery rates, differs from all the previous methods in that it makes no reference to the geology of the area under consideration. Instead, historical rates of discovery are used as data for extrapolation. A variety of data bases and coordinate systems have been utilized to make these extrapolations.

The primary drawback of this method is its inability to deal with areas for which vast amounts of historical data do not exist (e.g. Alaska or the Canadian frontiers). In addition, some of the extrapolations (e.g. Figures 2.4C and 2.4D) use time as one axis and, thus, appear to ignore the effects of changes in economics or governmental policy. More importantly, as can be seen from inspection of the figures, the data do not delineate clear trend lines. This has resulted in heated disputes about the most appropriate mathematical form of the projection (See, for example, the

---

(1) A trap is any barrier to the upward movement of oil or gas that allows either or both to accumulate. Stratigraphic traps result from changes in the rock types rather than from structural deformation.

exchange between Ryan [1965; 1966] and Hubbert [] ; 1966]). Thus, although such projections give the appearance of objective extrapolation, there exists some latitude in interpreting the general shape of the extrapolated curve.

Disciplinary Training

Disciplinary training, another of the independent variables, was operationalized through reference to the estimators final academic degree. In the case of estimates made by several individuals with a variety of backgrounds, the categorization was based upon the primary author's training (unless it was clear that another individual did the actual work). Although the estimates were produced by individuals with a variety of backgrounds (e.g. geology, economics, engineering, statistics and even one physicist), the vast majority (roughly 80 percent) were produced by geologists. Thus, for the purpose of this analysis, the variable has been collapsed into geologists and non-geologists.

Economic Assumptions

The independent variable "economic assumptions" has been used to capture differences along the Y-axis of the classification system shown in Figure 2.1. These assumptions were classified into three categories: 1) current levels of economics and technology, 2) a continuation of historic rates of change in economics and technology and 3) hypothetical future levels of economics and technology. Since the third category envisions a major break in either economics or technology that will facilitate increased recovery, these three types of assumptions form an ordinal scale that delineates progressively increasing inclusion of resources resulting from movement down the Y-axis of Figure 2.1.

Although the classification of economic assumptions has been based upon estimator's statements of their assumptions, it must be noted that 1) there is little evidence that different estimators mean the same thing when they refer to "present levels of economics and technology" and 2) the conception of "present levels of economics and technology" clearly changes through time. In short, while the ordinal differences among these types of assumptions carry necessary implications when comparing estimates made by the same individual at the same time, they do not carry any necessary implications when comparing estimates made by different individuals.

Organizational Affiliation

Organizational affiliation was operationalized in terms of the location of the estimator's employing organization within the network relations of an inter-organizational field. This perspective, adopted from the research on the relationship between organizations and their environments (e.g. Aldrich and Pfeffer, 1976; Aldrich, 1979; Perrow, 1979; Scott, 1981; Warren, 1967), focuses upon the relations that link a variety of different types of organizations within a specified geographic area. Specifically, this thesis focuses upon the dynamic relations between a subset of those organizations that make up the inter-organizational field (Warren, 1967) known as the international oil industry: i.e. oil and gas companies, the U.S. government, and the governments of oil-exporting underdeveloped countries (Tanzer, 1969).

Historically, oil and gas estimates have been made by the following types of actors: international oil and gas companies (majors and minors), industry consultants (organizations and individuals), banks, government agencies, government consultants (organizations and individuals), non-oil and gas energy companies and independent researchers (organizations and individuals). By classifying consultants with the organizational type for whom they are consulting, these actors can be classified into two major camps, the government and the oil and gas industry, on the basis of their affiliations with organizations in the inter-organizational field. If one places the banks with the oil and gas industry, the only exceptions to this categorization are the non-oil and gas energy companies and the independent researchers.(1) The implications of this fact are profound; the majority of actors engaged in the production of resource estimates in the U.S. can be identified with structural interests defined by the political economy of the world oil and gas industry.(2) For the purpose of the statistical analysis, estimators were assigned to one of four organizational categories: industry, government, independent, or Hubbert. The first three categories include estimators who were employed by organizations occupying the respective position in the inter-organizational field. The fourth category, Hubbert, includes the estimates of a single individual

---

(1) Although placing the banks with the oil and gas industry may appear problematic, there are a number of reasons for doing so: 1) U.S. banks are not government institutions, 2) U.S. banks share interlocking directorates with the oil and gas industry (Schaffer, 1983:259) and 3) the banks produce resource estimates for the same reason as the industry, to provide a guide for investment decisions.

(2) These interests and their implications will be specified and examined in detail in Chapter 5.

whose case is anomolous both in terms of his organizational affiliation (unlike other estimators he was not employed by a single organization at the time he produced his estimates) and the estimates he produced.

DATA

Table 2.2 presents the population of estimates of ultimately recoverable conventional(1) U.S. crude oil resources produced by estimators employeed within the United States(2) which have appeared during the 1940-1981 period. These estimates, their associated characteristics (i.e. estimation methodology, economic assumptions) and the characteristics associated with the estimators who produced them (i.e. disciplinary training, organizational affiliation) constitute the raw data that will be subjected to statistical analysis in this thesis. The following procedures have been followed in order to insure that the

---

(1) Conventionally recoverable oil excludes those deposits which exist in the form of tar sands, oil shale, etc.

(2) The relatively few estimates made by estimators employed outside the United States have been excluded on the basis that organizational affiliation may act as an intervening variable between aspects of the national social context and scientific practice (Anderson, 1981) and, hence, to include such estimates may confuse the present analysis. The relationship between organization and social context will be examined directly in Chapter 6.

TABLE 2.2: CHARACTERISTICS OF ESTIMATES AND ESTIMATORS

DATE	AUTHOR	ORG	OCC	METHOD	ECON	ESTIMATE
1942	PRA	Ind	Geo	V.Y.	0	100
1945	PRA	Ind	Geo	V.Y.	0	100
1948	WEE	Ind	Geo	G.A.	0	110
1950	PRA	Ind	Geo	V.Y.	0	142
1952	SCHU	Ind	Geo	E.H.	0	200
1953	MACN	Ind	Geo	G.A.	0	200
1955	AYR	Ind	Geo	G.A.	0	140
1956	MURR	Ind	Geo	V.Y.	0	200
1956	PRA	Ind	Geo	G.A.	0	170
1956	HUBB	---	Geo	G.A.	2	175
1956	POGU	Ind	Oth	Oth	0	165
1956	KNEB	Ind	Geo	Oth	0	173
1956	USDI	Gov	Geo	E.H.	2	300
1957	OGJC	Ind	Geo	V.Y.	0	150
1957	OGJC	Ind	Geo	V.Y.	0	300
1957	OGJC	Ind	Geo	V.Y.	0	200
1957	OGJC	Ind	Geo	V.Y.	0	300
1957	OGJC	Ind	Geo	V.Y.	0	310
1957	OGJC	Ind	Geo	V.Y.	0	325
1957	HIHA	Ind	Oth	Oth	2	250
1958	OGJO	Ind	Oth	V.Y.	2	300
1958	WEE	Ind	Geo	G.A.	0	204
1958	MILL	Gov	Geo	V.Y.	0	250
1958	DAV	Ind	Oth	E.H.	1	165
1958	NETS	Oth	Geo	V.Y.	2	390
1958	COHA	Ind	Oth	Oth	2	250
1959	WEE	Ind	Geo	G.A.	2	391
1961	AVER	Gov	Geo	G.A.	0	400
1962	HUBB	---	Geo	E.H.	1	175
1962	HUBB	---	Geo	F.S.	0	170
1962	MOO	Gov	Geo	E.H.	2	364
1962	ZA	Gov	Geo	V.Y.	2	590
1962	DEPI	Gov	Geo	V.Y.	2	457
1963	US	Gov	Geo	V.Y.	2	600
1963	I	Ind	Geo	G.A.	2	275
1963	MCKE	Gov	Geo	V.Y.	2	658
1963	LAND	Oth	Oth	G.A.	2	360
1964	MCAF	Ind	Oth	G.A.	2	275

(Table 2.2 continued on next page)

(Continued from previous page)

1965	MCKE	Gov	Geo	V.Y.	2	656
1965	HEND	Gov	Geo	V.Y.	0	355
1965	WEE	Ind	Geo	G.A.	0	270
1966	HUBB	---	Geo	E.H.	1	170
1966	LI	Ind	Geo	F.S.	2	240
1966	MOO	Gov	Geo	E.H.	2	300
1966	HEND	Gov	Geo	V.Y.	2	455
1967	HUBB	---	Geo	E.H.	2	170
1967	RYM	Ind	Geo	G.A.	2	200
1968	ELLI	Oth	Oth	E.H.	1	450
1969	HUBB	---	Geo	E.H.	2	165
1969	SCHW	Gov	Geo	V.Y.	0	405
1970	NATP	Ind	Geo	G.A.	2	384
1970	MOO	Ind	Geo	E.H.	2	353
1971	ARPS	Ind	Oth	E.H.	2	165
1971	HUBB	---	Geo	E.H.	2	160
1971	NATP	Ind	Geo	G.A.	0	271
1971	CR	Ind	Geo	G.A.	1	260
1972	NATP	Ind	Geo	G.A.	1	324
1972	DEPI	Gov	Geo	V.Y.	2	504
1972	THEO	Gov	Geo	V.Y.	0	523
1973	SCHW	Gov	Geo	V.Y.	2	555
1973	HUBB	---	Geo	E.H.	2	175
1973	NATP	Ind	Geo	G.A.	0	238
1974	BONI	Ind	Geo	G.A.	2	255
1974	HUBB	---	Geo	E.H.	2	172
1974	MOO	Ind	Geo	F.S.	0	199
1974	JOD	Ind	Geo	G.A.	2	200
1974	MCKE	Gov	Geo	V.Y.	0	369
1974	BERG	Oth	Geo	E.H.	1	355
1974	FORD	Oth	Geo	G.A.	2	583
1975	EXX	Ind	Geo	G.A.	1	216
1975	MOOD	Ind	Geo	F.S.	2	190
1975	MILL	Gov	Geo	V.Y.	1	206
1975	NATA	Oth	Geo	Oth	0	211
1975	SHE	Ind	Geo	G.A.	0	208
1975	RA	Oth	Oth	E.H.	1	170
1975	RA	Oth	Oth	E.H.	1	163
1975	RA	Oth	Oth	F.S.	1	155
1975	BROM	Oth	Oth	E.H.	1	215
1976	GROS	Gov	Oth	V.Y.	2	231
1976	LANG	Ind	Geo	G.A.	0	203

(Table 2.2 continued on next page)

(Continued from previous page)

1977	FOWL	Oth	Oth	E.H.	1	154
1977	FOWL	Oth	Oth	E.H.	1	180
1978	TANN	Oth	Geo	E.H.	2	179
1978	TANN	Oth	Geo	G.A.	1	166
1978	SHE	Ind	Geo	G.A.	0	192
1979	MAST	Gov	Geo	V.Y.	1	207
1979	HUBB	---	Geo	E.H.	2	163
1979	HALB	Ind	Geo	F.S.	0	193
1978	U	Gov	Oth	E.H.	1	198
1979	U	Gov	Oth	E.H.	1	198
1981	NEHR	Oth	Geo	F.S.	0	181
1981	WIOR	Oth	Oth	E.H.	1	161
1981	MAY	Oth	Oth	E.H.	1	150
1981	MAY	Oth	Oth	E.H.	1	150
1981	MAY	Oth	Oth	E.H.	1	175
1981	DOLT	Gov	Geo	V.Y.	1	223
1981	CARG	Gov	Geo	E.H.	1	213

CODES:

Organization (ORG):
Ind = Industry; Gov = Government; Oth = Other; --- = Hubbert

Occupation (OCC):
Geo = Geologist; Oth = Other

Method:
V.Y. = Volumetric Yield; G.A. = Geological Analogy; E.H. = Exploitation History; F.S. = Field Size; Oth = Other

Economic Assumptions (ECON):
0 = Current levels of economics and technology
1 = Continuation of current trends in economics and technology
2 = Hypothetical future levels of economics and technology

Estimate:
Numerical value expressed in billions of barrels

Author:
For specific references, see Appendix I

list is as complete as possible: a) a search of Petroleum Abstracts, b) inclusion of estimates from previous lists, c) interviews with active and retired resource estimators, d) bibliographic searches of the references found with published estimates, and e) examination of the proceedings of major meetings of petroleum geologists. These procedures, which have resulted in a list considerably longer than any previously published, lend validity to the treatment of this set as the population of publicly available estimates.(1)

A number of these estimates, as published, are not strictly comparable. The bases for this non-comparability can be traced to a number of elements: differences in the geographic definition of the United States, differences in the resource being estimated (i.e. total liquid hydrocarbons or crude oil), differences in the level of

---

(1) Although the list compiled can be considered the population of estimates in print, it should not be treated as the general universe of estimates. Many estimates were made for the internal consumption of the producing organization and, hence, were never published. In addition, estimates published only in house organs are not included. Although the type of estimate examined in this thesis is less likely to be treated as proprietary information than other types (e.g. estimates of the ultimate resources of a particular play or of resources existing on company lands), one must remain conscious of the distinction between the particular population examined here and the general universe of estimates of U.S. crude oil resources.

cumulative recovery expected, etc. Restricting the analysis to those estimates that are strictly comparable in their published form would drastically reduce the number of cases.(1) Thus, minor adjustments have been made to some of the estimates in order to facilitate the inclusion of all estimates of undiscovered conventionally recoverable U.S. crude oil while assuring that the adjusted figures are strictly comparable, i.e. that they all refer to precisely the same category -- the amount of conventional crude oil ultimately recoverable from the continental United States and the associated offshore regions. In other words, adjustments have been made when the differences among the published estimates are attributable to the inclusion or exclusion of relatively well known quantities for which there exist standard, consensually accepted reference figures (e.g. past production, proved

---

(1) This lack of strict comparability has also led to a considerable confusion about the magnitude of certain estimates since different authors frequently adjust estimates made by others in idiosyncratic manners so that the results are comparable with their own figures. In order to avoid such confusion the estimates cited within this thesis have been, to the extent possible, drawn from the original sources.

reserves, etc.)(1) Thus, some of the numerical values for estimates cited in Table 2.2 differ from the originally published values. For details of the adjustments made to specific estimates, see Appendix I.

Careful scrutiny of the list shows that certain names appear more than once and, on occasion, more than once in a given year. This occurs when estimators have conducted and reported the results of two or more conceptually independent estimates (i.e. estimates involving different estimation techniques, data sources, etc.).

The statistical analysis of this data, however, is not an ends in and of itself. Instead, statistical analysis will be utilized as a means to build a bridge between the characteristics of estimates and estimators and the historical form and content of resource estimation practice. Thus, data other than that presented above will also be included.

---

(1) It should be noted that there does exist a certain amount of contention among the standard reference figures and the differences among these figures have figured prominently in certain policy debates (Wildavsky and Tanenbaum, 1981). The relatively small magnitude of these differences, however, render them trivial in terms of the present analysis. Published estimates of proven reserves for the United States from a given year, for example, vary by less than 10 percent. Thus, if there were 40 billion barrels of proven reserves the figures for that year would differ by less than 4 billion barrels. In the analysis that follows, however, differences of as much as 50 billion barrels are treated not uncommon.

Data on the form and content of resource estimation practice have been drawn from two major sources: historical sources and personal interviews. The relevant historical materials include papers in which estimates were made and/or interpreted (either in terms of methodology or policy implications) and materials relevant to the historical changes in the political and economic environments of the United States oil and gas industry. Interviews were conducted with a number of key informants involved in either the production or interpretation of resource estimates. Although these interviews included individuals employeed by government, industry and independent organizations in the U.S. and Canada, no attempt was made to systematically interview either the entirety or a random sub-sample of the community of resource estimators. Thus, interview material has been used primarily as a means to corroborate interpretations of and fill lacunae in the existing historical materials.

SUMMARY

Naturalistic explanations are generally given for both the adoption of and changes in scientific knowledge. Recent developments in the history and philosophy of science, however, have removed the epistomological basis for the naturalistic account. These same developments suggest the possibility of a sociological explanation. Sociological explanations of the content of scientific knowledge have been of two major types: attributional models of how knowledge is constituted in a local context and interest models of why a community of individuals constitute knowledge in the same manner. According to the attributional model, the actual practices involved in the production of the estimates (e.g. estimation methodology) should account for the variation among the estimates. According to the interest model, characteristics of the estimator rather than characteristics of the estimate should account for the variation among the estimates. The following chapters apply statistical techniques to the data and measures outlined in the second half of this chapter in order to determine the relative utility of the attributional and interest models in explaining the historical pattern of U.S. crude oil resource estimates.

CHAPTER 3

PATTERN AND PROCESS IN THE HISTORY OF U.S. CRUDE OIL ESTIMATION

The preceding chapter delineated the raw data that will be subjected to statistical analysis in the remainder of this thesis. This chapter documents the existence of a particular pattern characterizing the distribution of the dependent variable and examines several plausible explanations for that pattern.

A PATTERN AND ITS CHARACTERISTICS

Figure 3.1 graphically displays a scatterplot of the population of estimates of ultimately recoverable conventional crude oil resources for the continental United States and its associated offshore areas. The X-axis corresponds to the year the estimate was published and the Y-axis corresponds to the magnitude of the estimate.(1)

Comparison of the estimates with others made at approximately the same time delineates three natural

---

(1) The precise magnitudes of these estimates are listed in Table 2.2.

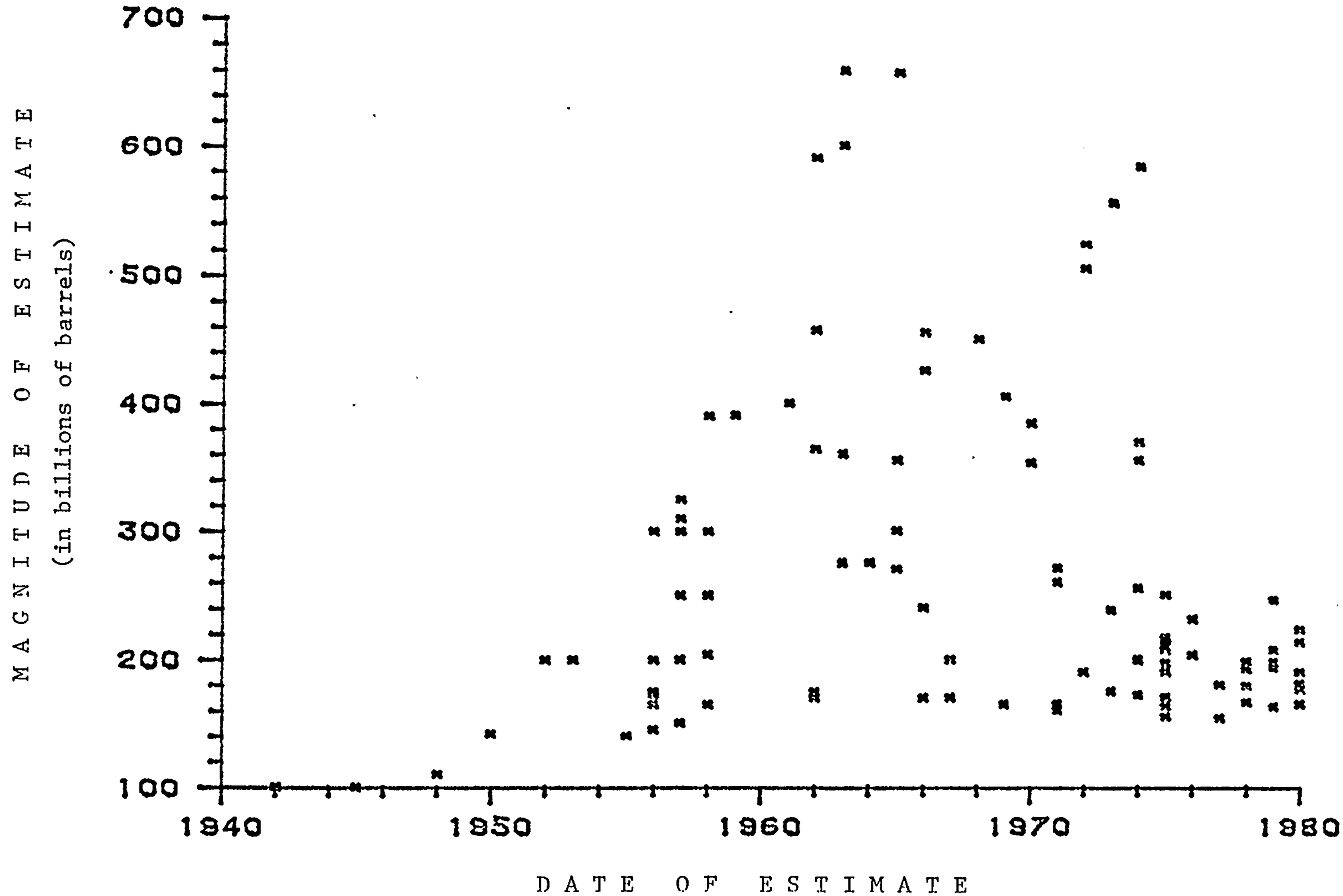


FIGURE 3.1: A SCATTERPLOT OF THE POPULATION OF ESTIMATES OF ULTIMATELY RECOVERABLE, CONVENTIONAL U.S. CRUDE OIL RESOURCES

groupings definable by the criteria of magnitude and variation (see Table 3.1). Period 1, from 1940 to 1956, is characterized by relatively low magnitude estimates (around 150 billion barrels) and a general consensus about the numerical value (a standard deviation of roughly 50 billion barrels). Period 2, from 1957 to 1974, is characterized by both an increasing variation among estimates made in a given year (a standard deviation of nearly 140 billion barrels) and an overall tendency toward higher estimates (a mean value of over 300 billion barrels). Period 3, from 1975 to 1981, shows a renewed consistency in the estimates (a standard deviation of 25 billion barrels) and a tendency toward intermediary magnitude estimates (a mean value of approximately 200 billion barrels). These characteristics, as shown in Figure 3.2, describe a particular pattern. We turn now to a more detailed examination of each of the three characteristics.

Timing of the Breaks Between Periods

Analysis of the scatterplot of estimate magnitudes highlights the importance of the dates 1956-7 and 1974-5; they represent points of transition between distinctly definable groupings of estimates. Although at least one estimate has been produced almost every year since the

TABLE 3.1: MEANS, STANDARD DEVIATIONS AND NUMBER OF CASES OF ESTIMATES OF ULTIMATELY RECOVERABLE U.S. CRUDE OIL RESOURCES (BILLIONS OF BARRELS) AS BROKEN DOWN ACROSS TIME.

TIME	MEAN VALUE	STANDARD DEVIATION	N
1940-1956	165.4	54.1	13
1957-1974	320.7	138.4	57
1975-1981	193.7	25.4	31
Total Population	261.7	126.1	101

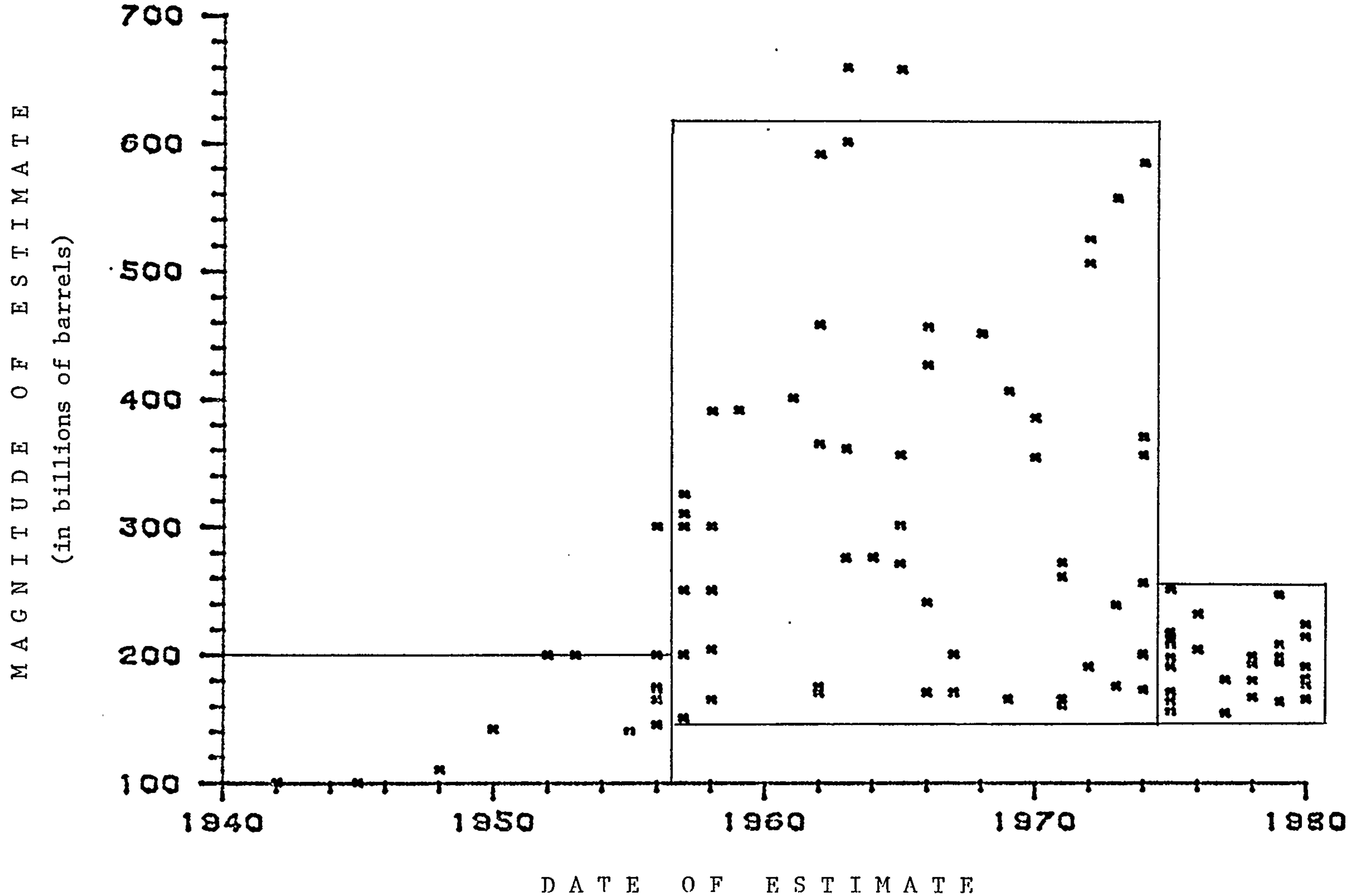


FIGURE 3.2: HISTORICAL PATTERN OF ESTIMATES OF ULTIMATELY RECOVERABLE, CONVENTIONAL U.S. CRUDE OIL RESOURCES

early 1950's, 29 of the estimates were produced in four years: 1956, 1957, 1974, and 1975. Stated another way, approximately 30 percent of the estimates were produced during 12 percent of the chronological period covered. This clustering of the production of estimates at two points in time, suggests that estimates attract more attention at some times than at others.

Examination of the relevant historical documents shows that these dates correspond to periods of increased methodological debate.(1) The 1956-7 debate centered upon differing assumptions about economics and technology. Some of the estimators (e.g. Hubbert, Ayres) interpreted the existing estimates as representing the ultimate amount of crude oil that would be produced from the United States irrespective of changes in economics and technology. Others (e.g. Weeks) interpreted the estimates as the ultimate amount of crude oil that could be produced given existing economics and technology, but expected changes in economic and technological conditions to lead to an upward revision of the figures as time progressed. In terms of Figure 2.1, the debate focused upon the interpretation of

---

(1) See, for example, Petroleum Week, 1956; Hubbert, 1956; Gonzalez, 1957; Oil and Gas Journal, 1957; West, 1974; Gillette, 1974; National Academy of Sciences, 1975; Joint Economic Committee, 1975.

the boundary between a) currently exploitable reserves and resources and b) marginal resources.

By contrast, the 1974-5 debate centered upon the geological constraints on the amount of oil potentially recoverable from very small pools. Some of the estimators (most notably McKelvey) held that there existed large amounts of potentially recoverable crude oil in very small pools which were not being exploited because they are not as economically profitable as larger pools. Other estimators (e.g. Moody, Jodry, Hubbert) held that the estimation technique utilized by McKelvey led to the inclusion of pools that were so small that the limits upon their production were geologic rather than economic or technological. In terms of Figure 2.1, the 1974-5 debate focused upon the delineation of a boundary between marginal and submarginal resources. Thus, the question being debated in these two cases was markedly different. In each case, however, the timing of the breaks between periods correlates with an increase in the number of resource estimates being produced and with a controversy over the correct magnitude of those estimates.

Mean Magnitude of the Estimates During a Period

The second major characteristic of the aggregate pattern is the change in mean magnitude of the estimates through time. The descriptive statistics in Table 3.1 suggest that this characteristic has changed in a curvilinear, rather than a linear, manner through time; it went up after 1956 and down after 1974. Attempts to develop statistical models describing the effects of independent variables upon the magnitude of the estimates immediately confront a technical problem. As can be seen from an examination of Figure 3.1, the estimates are not normally distributed. This fact precludes the use of ordinary least-squares regression analysis since the conditional variances of the variable are unequal thus violating the assumption of homoscedasticity underlying ordinary least-squares regression. Ordinary least-squares regression also assumes that the error of the estimate is normally distributed, another assumption that is clearly violated. Instead, the error structure for the distribution approximates a Poisson distribution.

A recently developed statistical analysis system, Generalized Linear Interactive Modeling (or GLIM), provides a means around these problems; it can estimate models with non-standard assumptions like Poisson distributions of error and heteroscedasticity (Baker and Nelder, 1978). Through use of a maximum liklihood estimation procedure and the assumption that the errors are distributed as the

Poisson, GLIM facilitates the estimation of models of the form

$$\log M = \Sigma\beta \log C + \xi_i$$

in which M is magnitude of the estimate and C is a characteristic of either the estimate or the estimator.

Table 3.2 examines the relationship between the date an estimate was made and the magnitude of that estimate. The curvilinear model with Poisson distribution of error terms yields a significantly better fit ($p < .001$) than any of the alternative linear and curvilinear models.(1) Thus, one can statistically model the curvilinear change in estimate magnitude through time.

Variation Around the Mean Magnitude

The third major characteristic of the aggregate pattern is the amount of variation around the mean

---

(1) It should be noted that dropping the 10 estimates made by one particular individual (Hubbert) imporves the fit of the curvilinear model with Poisson error structure considerably; the R-square increases from .3200 to .4231 and the standard error of the estimate (expressed as a natural log of the actual value) decreases from 6.08 to 5.67. This implies 1) that Hubbert made estimates which did not follow the curvilinear trend and 2) that the estimates of the majority of the estimators follow a more curvilinear trend than suggested by the results for the third model in Table 3.2. For a thorough examination of the implications of these two findings, see Bowden (forthcoming).

TABLE 3.2: BIVARIATE REGRESSION OF MAGNITUDE OF ULTIMATELY RECOVERABLE U.S. CRUDE OIL RESOURCES UPON DATE OF ESTIMATE.

INDEPENDENT VARIABLE (1)	ERROR STRUCTURE	R^2	D.F.	F (2)	STANDARD ERROR
Year	Normal	.0019	1/99	0.19	126.6
Year + Year^2	Normal	.2360	1/98	30.0 *	111.3
Year + Year^2	Poisson	.3120			

Note: All coefficients are maximum liklihood estimates computed with GLIM. An approximate R-square was estimated from the fitted model and the total scaled deviance.

1) Year = Date of publication - 1930
2) Ratio of scaled deviances divided by their degrees of freedom. The tests shown here are for increase in R-square over that associated with the preceding model. An F-test comparing the two curvilinear models is not technically possible since it is only the error structure which changes. The improvement in fit is evident, however, from a comparison of the R-square terms.

* $p < .001$

magnitude of the estimates at a given point in time. Unfortunately, so far as this author knows, there exist no statistical techniques designed for modeling changes in variance. Thus, it is necessary to approach the problem indirectly. Table 3.3 presents five separate models. The first four each express the zero-order effect of one of the four independent variables described in the preceding chapter (i.e. method, economics, organization, disciplinary training) upon the magnitude of estimates of ultimately recoverable U.S. crude oil resources. In most cases, the coefficients express deviations from the mean of a baseline category (e.g. industry in the case of organization). The exception to this is economics in which the coefficient is an unstandardized regression coefficient. Organization and method explain considerable portions of the variance and are significant at $p<.001$. Economic assumptions and disciplinary training show considerably less association. These results, although suggestive, are clearly an oversimplification since they treat the data as if it were cross-sectional.

The fifth model, time, displays the relationship between estimate magnitude and a dummy variable for the period in which the estimate was produced. Comparison of the R-square from this model (.3463) with that from the curvilinear-poisson model (.3120) shows that the dummy

TABLE 3.3: BIVARIATE REGRESSIONS OF MAGNITUDE OF ESTIMATES OF ULTIMATELY RECOVERABLE U.S. CRUDE OIL RESOURCES UPON CHARACTERISTICS OF ESTIMATORS AND ESTIMATES.

INDEPENDENT VARIABLE	COEFFICIENT	R^2	F (1)	D.F.
Organization		.372	19.2 **	3,97
Hubbert (c)	5.133			
Industry	.273			
Independents	.356			
Government	.824			
Occupation		.045	4.66	1,99
Geologist (c)	5.617			
Other	-.237			
Methodology		.214	8.8 **	3,97
Field-size/Other (c)	5.299			
Exploitation History	-.091			
Geological Analogy	.213			
Volumetric Yield	.541			
Economic Assumptions		.066	7.0 *	1,99
Constant	5.422			
Unstandardized B	.134			
Time		.346	25.9**	2,98
1940-1956 (c)	5.108			
1957-1974	.662			
1975-1981	.158			

Note: All coefficients are maximum liklihood estimates calculated with GLIM under the assumption that the error structure takes a poisson distribution. All coefficients, except those associated with economic assumptions, are interpreted as deviations from the mean of the reference category (c).

1) The tests shown here are for the null hypothesis that the mean magnitude of the estimate across categories of the independent variable equals the grand mean.

* $p < .02$

** $p < .001$

variable treatment accurately captures the change in mean magnitude through time. This fact suggests an alternative manner of examining the relationship between the various independent variables and the variation among estimates. If a two-way analysis of variance showed significant main effects for both time and another independent variable, this would imply that the second independent variable is responsible for some of the variation around the mean magnitude of the estimate associated with a given period. As we have seen, however, the amount of variation around that figure changes through time. Thus, for the independent variable to be able to fully account for the historical pattern, there must exist a significant interaction between the variable and time.

Table 3.4 addresses the question of whether or not the effects of the characteristics of the estimate or estimator vary over time. In other words, are there interactions between the independent variables and the period effect associated with the change in mean magnitude of the estimates through time? Only in the case of organization does the interaction model account for a significantly larger proportion of the variance in magnitude than does the corresponding main-effects model. This model accounts for nearly 80 percent of the variance, a much larger proportion than explained by any other model. These

TABLE 3.4: COEFFICIENTS OF DETERMINATION, F-RATIOS, AND DEGREES OF FREEDOM FOR MODELS OF MAGNITUDE OF ESTIMATE OF ULTIMATELY RECOVERABLE U.S. CRUDE OIL RESOURCES (NATURAL LOGS).

MODEL	R^2	F (1)	D.F.
O and T main effects only	.708		
O and T main effects and interactions	.780	4.92*	5,90
D and T main effects only	.357		
D and T main effects and interactions	.359	.12	2,95
M and T main effects only	.484		
M and T main effects and interactions	.551	2.19	6,89
E and T main effects only	.359		
E and T main effects and interactions	.367	.56	2,95

Note: Symbols are used as follows: O, organization; D, disciplinary training; M, methodology; E, economic assumptions; T, time. The number of degrees of freedom associated with the organization model does not equal the expected number because of a lack of observations in one particular cell and, hence, the aliasing of one interaction term (see Baker and Nelder, 1978:4.3).

1) F-ratio for increase in R-square based upon increase in the scaled deviance of the interaction model over the main effects model.

* $p < .001$

findings lend considerable credence to the suggestion that organization can be treated as an external variable that impacts upon the production of scientific knowledge. Examination of the graphical presentations displaying the category means for the best fitting model involving each of the variables (see Figures 3.3-3.5) shows that the organization-time interaction model provides the most accurate representation of the scatterplot of estimates in Figure 3.1.

EXPLAINING THE PATTERN

This section expands upon the various accounts that have been offered by resource estimators and others to explain the differences between two or more estimates in an attempt to explain the characteristics of the historical pattern of U.S. crude oil resource estimates and the associated empirical findings. The accounts are named after the independent variable that they adduce to explain the differences among estimates.

Classificatory Differences

A number of authors (e.g. Ion, 1975; McKelvey, 1975; Sheldon, 1975) have remarked upon the confused usage of terminology that characterizes the reserve and resource

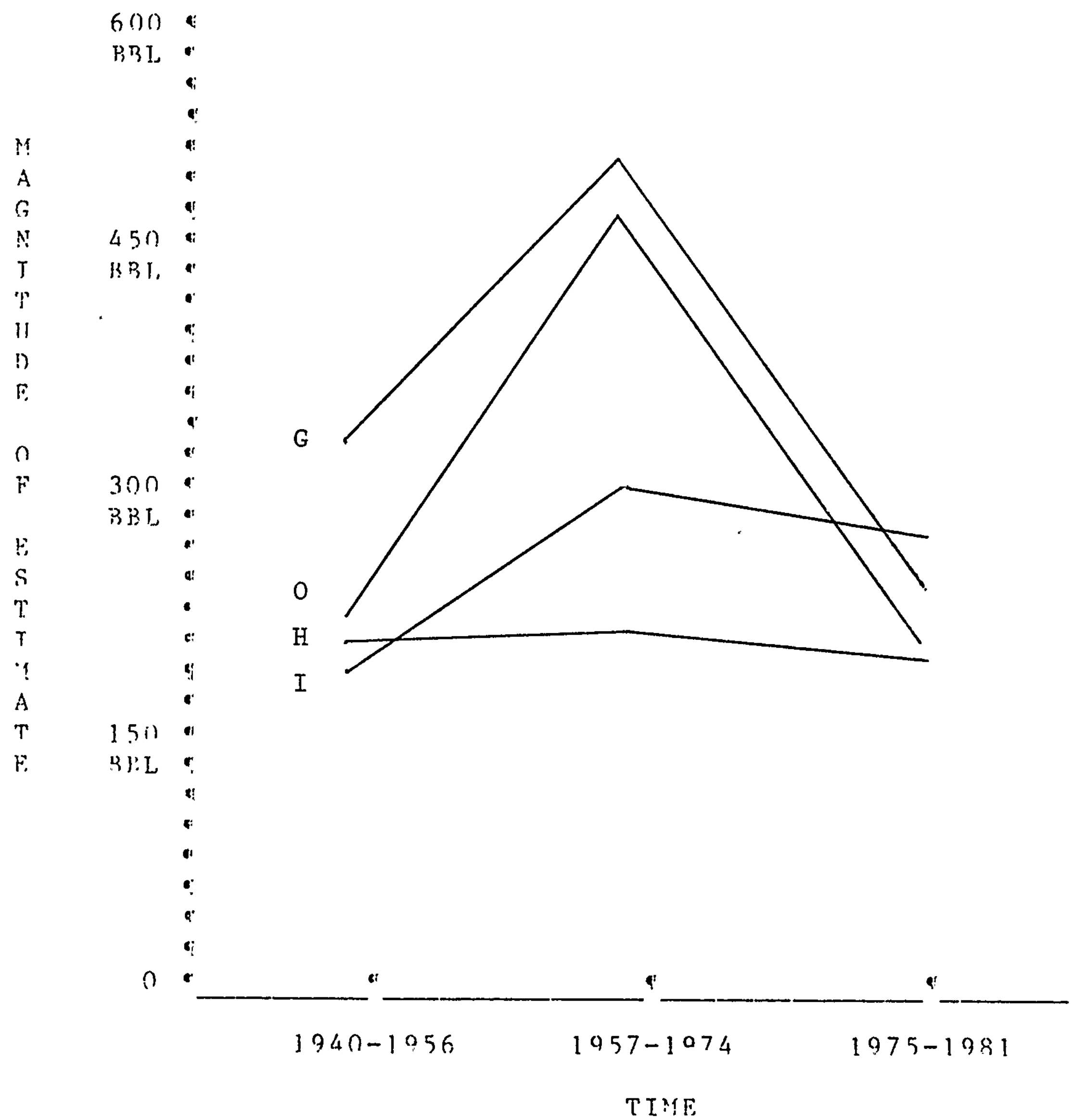


FIGURE 3.3: MEAN MAGNITUDE OF ESTIMATE OF ULTIMATELY RECOVERABLE U.S. CRUDE OIL RESOURCES EXPECTED FROM INTERACTION MODEL OF ORGANIZATIONAL TYPE AND TIME (BBL = BILLION BARRELS).

G = Government Estimates
I = Industry Estimates
H = Hubbert's Estimates
O = Independent Estimates

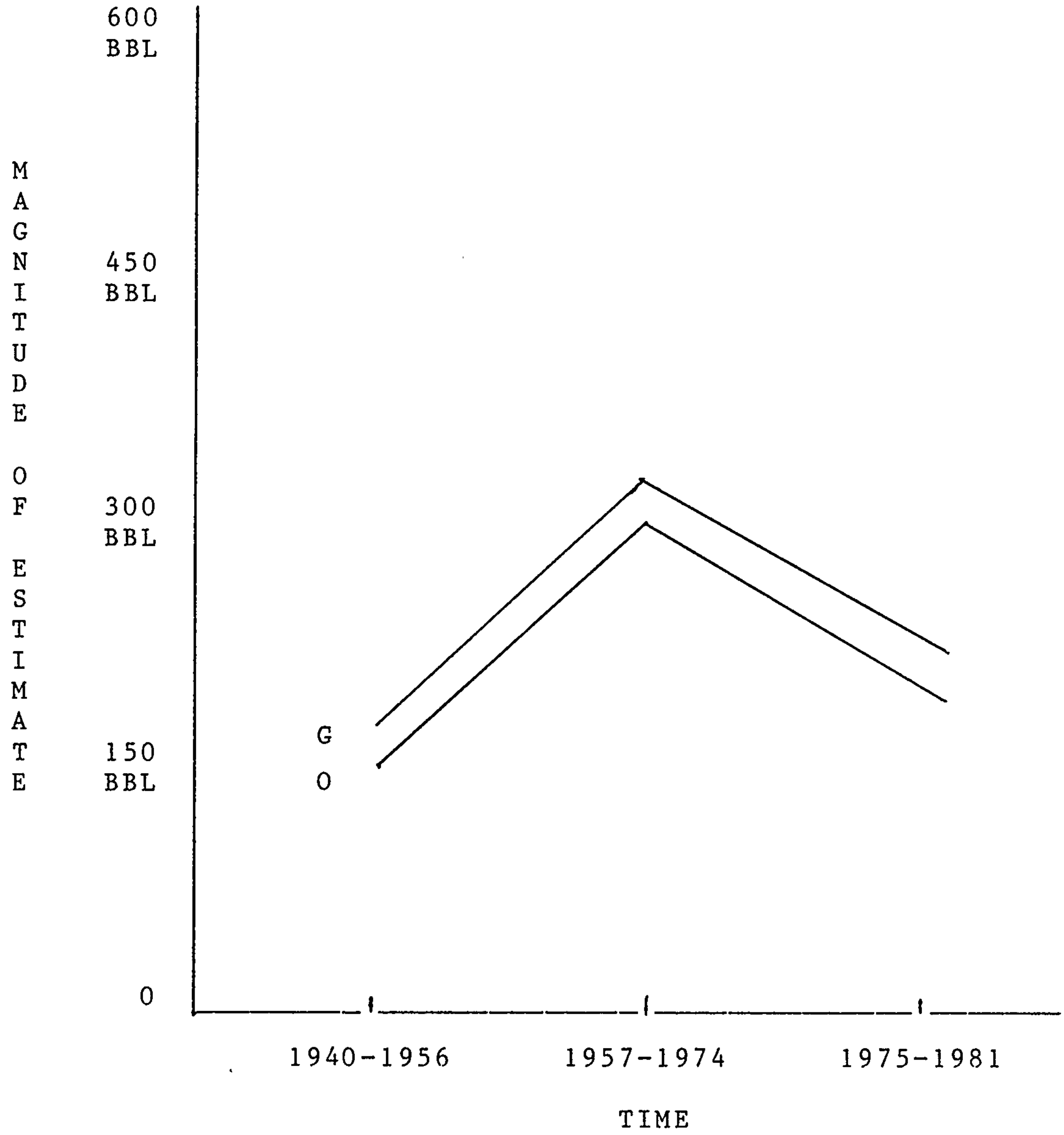


FIGURE 3.4: MEAN MAGNITUDE OF ESTIMATE OF ULTIMATELY RECOVERABLE U.S. CRUDE OIL RESOURCES EXPECTED FROM MAIN EFFECTS MODEL OF DISCIPLINARY TRAINING AND TIME (BBL = BILLION BARRELS).

G = Geologist
O = Other

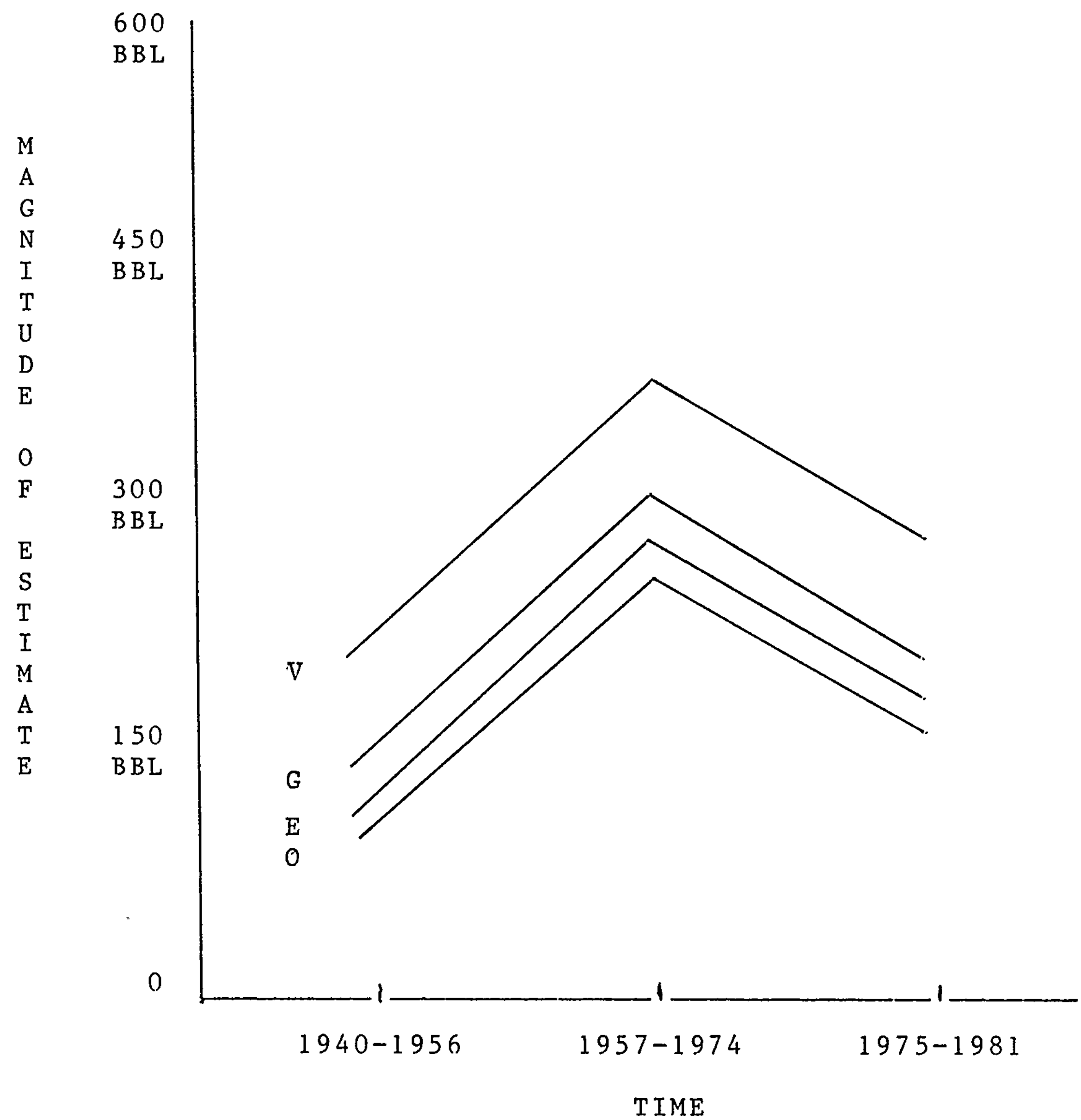


FIGURE 3.5: MEAN MAGNITUDE OF ESTIMATE OF ULTIMATELY RECOVERABLE U.S. CRUDE OIL RESOURCES EXPECTED FROM MAIN EFFECTS MODEL OF METHODOLOGY AND TIME (BBL = BILLION BARRELS).

G = Geological Analogy
V = Volumetric Yield
E = Exploitation History
O = Field-Size/Other

estimation literature. Proponents of the classificatory differences account (e.g. Sheldon, 1975) suggest that estimates differ because terminological confusion results in the improper comparison of estimates that are not conceptually compatible. Thus, following the logic of this account, most of the differences among the estimates should dissolve when conceptually similar estimates are compared. Since all of the estimates included in the aggregate pattern were adjusted to refer to the same conceptual category, the volume of ultimately recoverable conventional crude oil, the classificatory differences account is inapplicable; classificatory differences cannot be used to explain differences within a classificatory category.

Geographical Differences

Like the classificatory differences account, this explanation is inapplicable; the estimates have been adjusted to refer to the same basic geographic area (i.e. the continental United States and its associated offshore areas). This is a conservative definition of the geographic United States in that it excludes the least explored areas (i.e. Alaska). Certain minor differences, mainly relating to the extent of the offshore areas included in the estimate, remain but these differences are empirically inadequate in explicating the trend associated with the average magnitude of the estimates through time. In general, the geographic area of search has expanded through time and, hence, more potentially petroliferous areas were included in the later estimates. Thus, the drop in the average magnitude of the estimates following 1974 empirically contradicts this explanation.

Methodological Differences

As was evident from the descriptions in the previous chapter, a variety of methods have been used to estimate U.S. crude oil resources. The methodological differences account refers to this one particular aspect of the estimator's scientific practice in order to explain the differences among the estimates. Thus, it is argued that certain estimation techniques are "biased" toward relatively high or low estimates. In particular, estimates based upon the volumetric methodology are characterized as "high" (see, Hubbert, 1978) while estimates based upon exploitation history are characterized as "low" (see, Sheldon, 1975). While both of these characterizations have in general been true (see Table 3.3), any deterministic application of this account is an oversimplification. Close examination of the evidence shows the existence of exploitation history estimates that have been relatively high (e.g. Moore, 1962; Elliot and Linden, 1968) and volumetric estimates that have been relatively low (e.g. Miller, et. al., 1975; Dolton, et. al., 1981). Thus, methodological differences may be a necessary condition for explicating the differences among estimates but that factor alone cannot be sufficient.

This conclusion harmonizes with the results obtained when one attempts to explain the empirical pattern through reference to the logic of the methodological differences account. According to that account, we would predict that the relative magnitude of the mean estimate across time would vary directly with the proportion of estimates that yield "high" estimates (i.e. volumetric and geologic analogy estimates). Thus, the period from 1957-74 should be characterized by a higher proportion of estimates based upon these methods than either of the other periods. Examination of the historical utilization of various estimation methodologies partially confirms this prediction. Geologic analogy and volumetric yield based estimates accounted for 65 percent of the estimates made between 1957 and 1974 while accounting for 77 percent of the estimates made prior to that time and only 35 percent of the estimates made after that time (see Table 3.5). Thus, methodological differences may account for the drop

TABLE 3.5: THE PERCENTAGE OF ESTIMATES PRODUCED BY VARIOUS METHODOLOGIES DURING THREE PERIODS IN TIME.

	CHRONOLOGICAL	PERIOD	
METHODOLOGY	1940-56	1957-74	1975-81
Volumetric Yield	31%	37%	16%
Geological Analogy	46	28	19
Exploitation History	15	26	45
Field-size	0	5	16
Other	8	4	3
	N = 13	N = 57	N = 31

in magnitude after 1974 but do not provide any basis for explaining the rise in magnitude following 1956.

In relation to the question of variation among the estimates, the methodological differences account predicts that the number of distinct methodologies in use during a period will be inversely proportional to the consensus among the estimates. Thus, the period from 1957-74 should be characterized by the use of a wider variety of estimation methodologies than either of the other periods. Again, the facts only partially conform to the predictions. Although the number of estimation techniques in use increased between the first and second period with the introduction of field-size analysis, the variety of techniques in use has not changed since the early 1960's. Thus, while the relative frequency of use of a particular methodology varies through time, the utilization of these same types of methodology has been invariant since 1960. Thus, the proliferation of methodologies may account for the increase in variation associated with the transition between the first and second period, but it cannot account for the decrease in variation that accompanies the third period.

Finally, in relation to the timing of the breaks between the periods, the methodological differences account predicts that 1) the breaks will be accompanied by an intensification of methodological debate within the scientific community and that 2) a change in the utilization of particular methodologies will occur across the breaks. Thus, the account correctly predicts the intensification of interest in resource estimation and the associated increase in methodological debate that correlates with the breaks in the patterns but the account does not provide any basis for explaining the <u>timing</u> of the breaks between periods. As for the existence of notable changes in the utilization of estimation methodologies across the breaks in periods, such transitions do occur. The relative utilization of exploitation history analysis has progressively increased while the relative utilization of geological analogy has progressively decreased through time. The relative use of volumetric yield methods, while roughly constant through the first two periods, fell dramatically after 1974 (see Table 3.5). These shifts, however, reflect changes in the aggregate utilization of methodologies that are not evident at the individual level. If one compares estimates made on each side of a break by the same individual, it is evident that for most individuals the value of the estimate changes while the method used to produce it does not (see Table 3.6). Thus, the relationship between methodology and changes in the magnitude and distribution of estimates appears to be more

TABLE 3.6: A COMPARISON OF CHANGES IN THE MAGNITUDE AND THE METHODOLOGY OF REPEATED ESTIMATES MADE BY THE SAME INDIVIDUAL OR ORGANIZATION ACROSS THE BREAKS BETWEEN PERIODS.

ESTIMATOR	DATE	METHOD	MAGNITUDE
Weeks	1948	G.A.	110×10^9
	1958	G.A.	204
	1959	G.A.	391
Hill (and others)	1956	O	165
	1957	O	250
Hubbert	1956	G.A.	175
	1962	E.H.	175
	1962	F.S.	170
	1974	E.H.	172
	1979	E.H.	163
U.S. Geological Survey (various estimators)	1972	V.Y.	523
	1974	V.Y.	369
	1975	V.Y.	206
	1975	V.Y.	250
	1981	V.Y.	223
Moody	1974	F.S.	199
	1975	F.S.	190

Note: Symbols are as follows: G.A., geological analogy; E.H., exploitation history; V.Y., volumetric yield; F.S., field-size; O., other. All estimates represent barrels of crude oil ultimately recoverable from the continental United States and associated offshore areas.

complex than the methodological differences account suggests.

To summarize, the methodological differences account provides a basis for deriving expectations about each of the traits that characterize the historical pattern and, in several cases, these expectations correspond with the empirical data. The inability of the account to adequately explain the entirety of the historical pattern, coupled with the fact that a particular type of estimation methodology does not necessarily yield estimates that fall within a range notably smaller than the range covered by the aggregate pattern, suggests that the methodological differences account is in and of itself an insufficient explanation for the historical pattern.

Economic Assumptions

Economic assumptions, like methodology, are an internal feature of scientific practice that estimators frequently adduce to explicate the difference between estimates (see, for example, Netschert, 1958; Ryan, 1966). This account claims that the various estimates make reference to the same geology and that the differences in magnitude between the estimates stem from the differential inclusion of "marginal resources". The extent to which marginal resources have been included within an estimate, by definition, reflects the economic assumptions that have been adopted (see Figure 2.1).

This account has a strong logic to it and that logic is universally reflected when comparing estimates made by the same individual at the same time that involve distinct economic assumptions (see, for example, the estimates made by Weeks, 1959). The crucial presumption of this account is that the same sort of referential coherence occurs across estimators. In other words, the account presumes that everyone means precisely the same thing when they refer to "current levels of economics and technology" or to secondary recovery attributable to "hypothetical future levels of economics and technology." The relatively weak empirical relationship between economic assumptions and the magnitude of the estimates documented in Table 3.3, however, stands as convincing evidence that the presumed referential consistency does not exist.

Occupational Ideology

Research in the sociology of occupations has demonstrated the existence of occupational ideologies, i.e. attitudes and folkways that characterize the individuals who hold a particular occupational status (Caplow, 1954:124-141). Similarly, Robbins and Johnston (1976) have shown that disciplinary training impacts upon the content of science. Since geologists occasionally refer to themselves as optimists (see, for example, Hall, 1960; Parker, 1961), geologists might make larger estimates than individuals with other types of occupational training. Similarly, since bankers are concerned with financial return rather than mere physical existence, one might hypothesize that they would produce more conservative estimates. Although plausible, the empirical inadequacy of the disciplinary training variable (see Table 3.3) suggests its inapplicability in the present case.

Industry Bias

The industry bias account (e.g. Sherrill, 1974) holds that the industry manipulates the magnitude of the estimates in order to justify their desired pricing policy. Thus, in periods of oversupply and falling prices the industry makes low estimates of remaining resources in order to justify conservation and prop up the price structure. In periods of high prices, however, the industry makes large estimates of recoverable resources because the high prices expand that portion of the resource base that is economically exploitable. According to this account, government and other non-industry estimates cannot be trusted because they are ultimately dependent upon data provided by the industry. Thus, this account treats the political economy of the source of information as the primary factor responsible for the variation among natural resource estimates.

Although providing an interesting account of the changes in estimates through time, the industry bias account shows little empirical validity when explaining the aggregate trend. Prices for oil began to decrease (in constant dollar terms) around 1956 (when estimate magnitudes began to rise) and skyrocketed in 1974 (when estimate magnitudes began to fall)(Rustow, 1982:16-17,107). Thus, the relationship between the aggregate trends among the estimates and the price of crude oil is actually the inverse of the relationship specified by the industry bias account. Unlike the other accounts, however, the industry bias account does provide an explicit basis for explaining the timing of the breaks between the periods; the breaks occur as a function of changes in the political economic environment of the oil industry.

A second major problem with the industry bias account results from the inability of the account to explain the variation among estimates that are produced at approximately the same time. According to the industrial bias account, estimates made at roughly the same time by different organizations should harmonize because they share the same essential interests or are based upon data provided by organizations with those interests. A cursory examination of Figure 3.1 shows that no such consensus existed during the period 1957-74. Of equal significance, this account implies that the industry bases their exploration decisions upon data that they themselves know to be erroneous. Thus, when attempting to explain the changes in mean magnitude and variation around it, the industry bias account raises as many questions as it answers.

SUMMARY AND SYNTHESIS

Examination of each of the preceding accounts has led to the same conclusion; that account by itself cannot explicate all of the traits that characterize the aggregate distribution of resource estimates. A number of the accounts do, however, provide partial explanations. The methodological differences account, for example, harmonizes both with the empirical finding of a strong relationship between methodological type and the magnitude of the estimate and with the fact that estimators view methodological differences as important. The detailed examination of other accounts has pointed to interesting paradoxes. Economic assumptions, despite the fact that they were fundamental to the content of the 1956-7 controversy and that estimators frequently view them as the basis of differences between estimates, do not display a strong empirical relationship with the magnitude of the estimate. Similarly, the industry bias account, the only existing account of the production of resource estimates which makes reference to organization as a factor, does not appear applicable despite the fact that organizational type displays a strong empirical relationship with estimate magnitude.

From the examination of these diverse explanatory accounts we can draw several conclusions. First, a number of the accounts (e.g. classificatory, geographic, and occupational differences) have been shown to be totally inapplicable. Second, as we might have suspected, no single determining factor provides an adequate explanation for the complex pattern shown in Figure 3.2. This suggests the importance of generating an account that draws upon a number of the factors. The various accounts could be grouped together in one of two ways; individual accounts could be adduced in an ad hoc manner to explicate specific aspects of the pattern or, alternatively, they could be synthesized into a larger framework. Given the desirability of both avoiding ad hoc explanation and attaining parsimony, the latter course is clearly preferable. Third, if the synthetic account can dissolve the apparent paradoxes that have arisen through the examination of the individual accounts, this will stand as strong corroboration of the utility of the explanation. It is to the elaboration of such a synthetic account, the core assumptions account, that we now turn.

The Core Assumptions Account

Ascher (1978) proposed the core assumptions account on the basis of a critical examination of the accuracy of over 2000 forecasts that were drawn from a number of diverse contexts including resource estimation. He concluded that the major determinants of an estimate are its "core assumptions", i.e. the estimator's basic outlook upon the context within which the specific forecasted trend develops. This account differs from the use of methodology as an explanatory variable because it treats methodologies as the vehicles for determining the consequences and implications of pre-chosen assumptions. Thus, since certain resource estimation techniques have historically been associated with certain core assumptions, one can both explain the <u>tendency</u> of certain methods to yield "high" or "low" estimates and the failure of those methods to <u>necessarily</u> yield "high" or "low" estimates. From this it follows that when the choice of assumptions accurately reflects the future context, the choice of methodology is of relatively minor importance. Alternatively, if the core assumptions fail to capture the reality of the future context, then other factors (e.g. methodology) make relatively little difference.

The core assumptions account may appear to be circular; it is not. There are rare examples of accurate assumptions being matched with inappropriate methods to yield inaccurate forecasts (e.g. electrical demand forecasts made by the U. S. Federal Power Commission during the 1970's), of inaccurate core assumptions leading to accurate forecasts for at least part of the period of projection (e.g. Pearl's forecasts of population growth), and of inaccurate core assumptions cancelling one another and leading to accurate forecasts (e.g. the 1935 American Petroleum Institute forecast of 1945 passenger car registrations based upon an under-estimate of population growth and an over-estimate of the ratio of registered automobiles per person). Thus, as Ascher (1978:200) concludes,

> these rare cases demonstrate that the usually greater importance of core assumption accuracy is not a matter of definition, but rather is an empirical fact resulting from the variation in conceivable core assumptions, the practical differences that competing core assumptions make in forecast outcomes, and the relatively small practical effects of differences in methodology or source.

Ascher has also outlined several factors that affect the likelihood that the core assumptions will turn out to be accurate: 1) the interconnectedness of forecasting tasks, 2) the backwardness of sociopolitical forecasting and 3) the problem of "assumption drag". As it turns out, most forecasts are not a single projection, but rather a composite of several different projections. Thus, in the case of natural resource estimates, projections must be made not only of geological occurrence, but also of future economic conditions and technological developments. The problem is that the assumptions associated with these secondary projections are often subject to greater uncertainty because the estimator is not knowledgeable in those particular areas. Similarly, forecasts of recoverable oil are intimately intertwined with assumptions about future regulatory and taxation policies. Although estimators of petroleum resources have increasingly recognized this fact in the abstract (e.g. Haun, 1975; White and Gehman, 1979), few explicitly incorporate such sociopolitical features into their estimates.

More central to an explanation of the historical pattern of estimates is the concept of "assumption drag" (i.e. the reliance upon old core assumptions that have been invalidated). According to Ascher, this phenomenon accounts for many of the more drastic forecasting errors.

It occurs for several reasons. First, specialist forecasters often rely upon outdated assumptions for their secondary forecasts. Second, the cost of forecasting often necessitates a reliance upon outdated data. More specifically within the oil and gas industry, the most current data are held within the privilege of the company. Thus, a lag occurs between the time the information becomes available to the proprietary company and the time it becomes available to the industry as a whole or to the government. Third, and most profoundly, estimators can never be sure whether or not recent data represent a pattern that invalidates the previous one. Clearly, one cannot treat every deviation from the past pattern as a negation of the old pattern because it may turn out to be merely a minor or temporary fluctuation. Thus, many forecasters <u>intentionally</u> <u>ignore</u> deviations from their core assumptions if they have reason to believe that such deviations are temporary. Thus, when hindsight shows that the deviations were not temporary but, rather, the reflection of a major structural change, the forecaster appears to have been either conservative or inattentive.

Ascher (1978:116), in his analysis of the historical pattern of forecasts of 1975 energy demand, provides an illustration of this process. The failure of such estimates to anticipate the effects of the supply shortages and increased prices of 1973-74 closely parallels the situation examined in this thesis and, hence, warrants attention. Throughout the 1960's and early 70's energy forecasters steadily adjusted their 1975 demand projections upward on the basis of continuing increases in energy use. Thus, rapid growth in demand at the time that the projection was made led forecasters to project rapid growth in demand into the future. By 1965 the forecasts had reached the level that ultimately proved to be correct for 1975 demand, but this level was continually revised upward as a result of continued increases in energy consumption. Thus, after 1965 the extension of the business as usual assumption placed the expected 1975 demand at a higher level than the actualized 1975 demand which was dampened by the unforseen supply shortages and the associated increases in price.

According to Ascher (1978:107-108) the two crucial points in this explanation are:

> first, that forecasters "learn" most from current trends and adjust their expectations accordingly; and, second, that the structural change in the role of energy in the American economy (i.e. cost, limitations, and importance of energy and energy considerations) was not anticipated either quantitatively or qualitatively. This same dynamic of adjustment provided increasingly accurate forecasts for 1970 levels of energy consumption. But the 1973-74 shift in the energy balance was not (and could not be) anticipated or accommodated through adjustments based on "current experience" prior to 1973.

Thus, Ascher's account provokes an examination of several issues relevant to an understanding of the historical pattern of U.S. crude oil estimates: How do forecasters arrive at their "current experience"? What causes them to alter their core assumptions? How are new core assumptions arrived at? These are questions about the social construction of reality.

The following chapters elaborate upon the relationship between the core assumptions account and the historical pattern by utilizing aspects of that account to explicate the three characteristics of the historical pattern. Chapter 4 shows that the change in the mean magnitude of the estimates through time results from the estimator's changing interpretation of "current experience" and draws upon the relationship between both organization and methodology with current experience to explain the variation around the mean magnitude of the estimates produced at a given point in time. Chapter 5 explains the timing of the breaks between periods by tying the changes in core assumptions to changes in the political economy of the international oil industry.

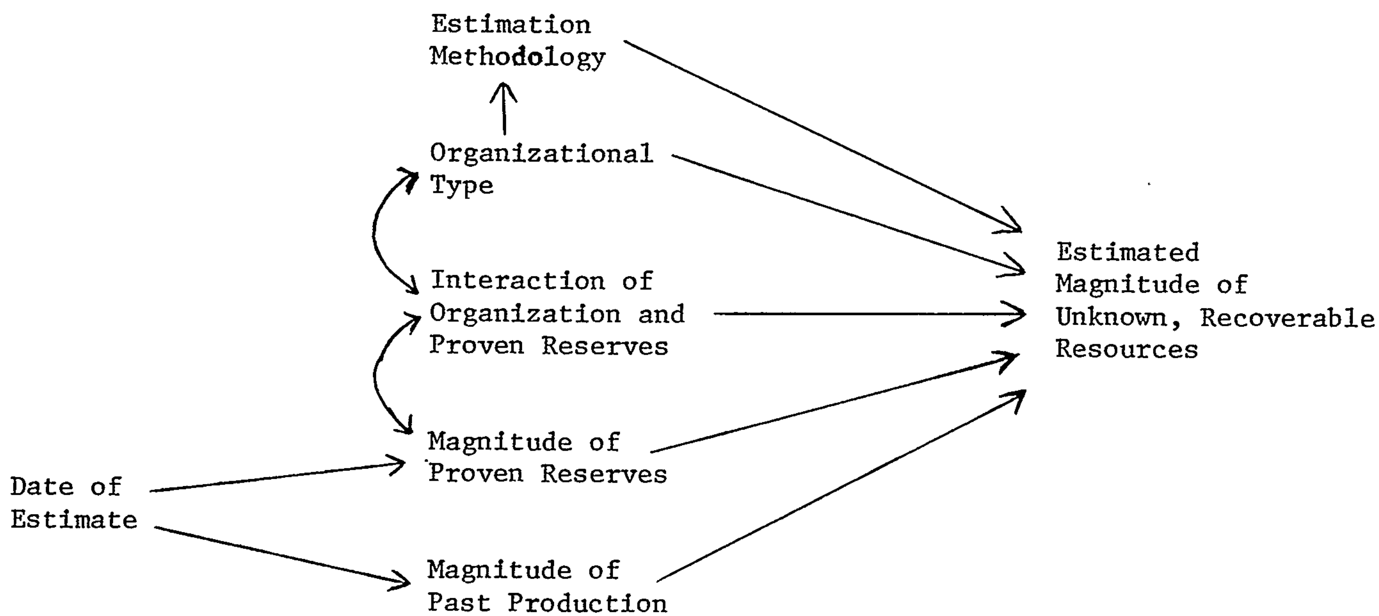
CHAPTER 4

APPLYING THE CORE ASSUMPTIONS ACCOUNT

The previous chapter examined several plausible accounts in an attempt to explain the differences among resource estimates. This chapter expands upon two features of the core assumptions account, the criteria used to establish the estimators "current experience" and the factors that lead estimators to extrapolate from their current experience in markedly different ways, in order to document the utility of that account in explaining the historical pattern of U.S. crude oil resource estimates. In doing this we move from the use of statistics as a means to describe a phenomenon needing explanation to the use of statistics as a means to explain that phenomenon.

Figure 4.1 provides a schematic representation of the theoretical relationships examined in this chapter. The first section of the chapter argues that the trend common to all of the estimates through time, i.e. that which can be attributed to a shared notion of current experience, reflects changes in the movement between categories of the total estimate. The second section of the chapter examines

FIGURE 4.1: A SCHEMATIC REPRESENTATION OF THE THEORETICAL RELATIONSHIPS AMONG THE EMPIRICAL CONSTRUCTS EXAMINED IN THIS CHAPTER.



the interrelationships among the shared bases of current experience and the factors that lead estimators to extrapolate from that experience in markedly different manners (e.g. the effects of estimation methodology and organizational type).

THE BASES OF CURRENT EXPERIENCE

According to Ascher (1978), estimators select their core assumptions upon the basis of criteria embedded in their current experience. Up until this point we have treated the estimates in terms of a standardized unit, the volume of ultimately recoverable conventional crude oil resources. While this usage facilitates a direct comparison of the estimate magnitudes, it hides the fact that the estimates were produced at different times and, hence, the fact that the estimators were working with different conceptions of "current experience" when the estimates were made. Thus, while the comparison of estimate magnitudes across time is descriptively useful because it displays the curvilinear nature of the changes in estimate magnitude, such a comparison is causally misleading because it erroneously suggests that time per se may account for the changes in estimate magnitude. As Blalock (1969:71) has noted, "expressing a change in X as a function of time is an admission of one's ignorance as to the causal dynamics." Time, as it has been used up to this point, functioned as a descriptively useful black box that reflected the operation of an ongoing process through time. Any meaningful explanation, however, must specify the underlying causal dynamics.

Disaggregating the Estimates

Table 4.1 disaggregates the estimates of ultimately recoverable crude oil resources into their three component parts: past production, proven reserves and unknown recoverable resources.(1) Table 4.2 fits linear and curvilinear models (with poisson distribution of error terms) to each of the three components of the total estimate. In each case the curvilinear model provides a better fit ($p < .001$). For both proven reserves and the estimates of unknown, recoverable resources the trends are predominantly curvilinear across time; the quadratic function accounts for increases of 67.9 percent and 31.7 percent in the variances explained in comparison to the linear functions which explained 22.3 and 6.0 percent

---

(1) As with the total estimates, oil attributable to Alaska has been excluded from the figures for past production and proven reserves and from the estimates of unknown recoverable resources.

TABLE 4.1: ESTIMATES OF ULTIMATELY RECOVERABLE CONVENTIONAL U.S. CRUDE OIL RESOURCES BROKEN DWON INTO THREE COMPONENT PARTS: PAST PRODUCTION, PROVEN RESERVES, AND UNKNOWN RESOURCES.

DATE	ESTIMATOR[1]	PAST[2]	PROVED[2]	UNKNOWN	TOTAL
1942	Pratt	25.2	11.0	63.8	100.0
1945	Pratt	29.8	16.0	54.2	100.0
1948	Weeks	35.1	21.4	53.5	110.0
1950	Pratt	38.9	24.6	78.5	142.0
1952	Schultz	43.1	27.5	129.4	200.0
1953	MacNaughton	45.3	28.0	126.7	200.0
1955	Ayres	49.9	29.6	60.5	140.0
1956	Murrell	52.3	30.0	117.7	200.0
1956	Pratt	52.3	30.0	62.7	145.0
1956	Hubbert	52.3	30.0	92.7	175.0
1956	Pogue and Hill	52.3	30.0	82.7	165.0
1956	Knebel	52.3	30.0	90.7	173.0
1956	Dept. of Interior	52.3	30.0	217.7	300.0
1957	OGJ, Company A	54.9	30.4	64.7	150.0
1957	OGJ, Company B	54.9	30.4	214.7	300.0
1957	OGJ, Company C	54.9	30.4	114.7	200.0
1957	OGJ, Company D	54.9	30.4	214.7	300.0
1957	OGJ, Company E	54.9	30.4	224.7	310.0
1957	OGJ, Company F	54.9	30.4	239.7	325.0
1957	Hill, et.al.	54.9	30.4	164.7	250.0
1958	Oil & Gas Journal	57.4	30.3	212.3	300.0
1958	Weeks	57.4	30.3	116.3	204.0
1958	Miller	57.4	30.3	162.3	250.0
1958	Davis	57.4	30.3	77.3	165.0
1958	Netschert	57.4	30.3	302.3	390.0
1958	Coqueron, et.al.	57.4	30.3	162.3	250.0
1959	Weeks	59.8	30.5	300.7	391.0
1961	Averitt	64.7	31.6	303.7	400.0
1962	Hubbert	67.2	31.8	76.0	175.0
1962	Hubbert	67.2	31.8	71.0	170.0
1962	Moore	67.2	31.8	265.0	364.0
1962	Zapp	67.2	31.8	491.0	590.0
1962	Nat. Fuels & Energy	67.2	31.8	358.0	457.0

(Table 4.1 continued on next page)

(Table 4.1 continued from previous page)

1963	Geological Survey	69.8	31.4	498.8	600.0
1963	Ion	69.8	31.4	173.8	275.0
1963	McKelvey	69.8	31.4	556.8	658.0
1963	Landsberg	69.8	31.4	258.8	360.0
1964	McAfee and Davis	72.4	31.0	171.6	275.0
1965	McKelvey & Duncan	75.1	31.0	549.9	656.0
1965	Hendricks	75.1	31.0	248.9	355.0
1965	Weeks	75.1	31.0	163.9	270.0
1966	Hubbert	77.8	31.4	60.8	170.0
1966	Link	77.8	31.4	130.8	240.0
1966	Moore	77.8	31.4	315.8	425.0
1966	Hendricks, et.al.	77.8	31.4	345.8	455.0
1967	Hubbert	80.6	31.5	57.9	170.0
1967	Ryman	80.6	31.5	87.9	200.0
1968	Elliot	83.7	31.4	334.9	450.0
1969	Hubbert	86.8	30.7	47.5	165.0
1969	Schweinfurth	86.8	30.7	287.5	405.0
1970	N.P.C.	90.0	29.6	264.4	384.0
1970	Moore	90.0	29.6	233.4	353.0
1971	Arps, et.al.	93.3	29.0	42.7	165.0
1971	Hubbert	93.3	29.0	37.7	160.0
1971	N.P.C.	93.3	29.0	148.7	271.0
1971	Cram	93.3	29.0	147.7	260.0
1972	Jodry	96.6	28.1	65.3	190.0
1972	Dept. of Interior	96.6	28.1	379.3	504.0
1972	Theobald, et. al.	96.6	28.1	398.3	523.0
1973	Schweinfurth	99.9	26.3	428.8	555.0
1973	Hubbert	99.9	26.3	48.8	175.0
1973	N.P.C.	99.9	26.3	111.8	238.0
1974	Bonillias	103.1	25.3	126.6	255.0
1974	Hubbert	103.1	25.3	43.6	172.0
1974	Moody	103.1	25.3	70.6	199.0
1974	Jodry	103.1	25.3	71.6	200.0
1974	McKelvey	103.1	25.3	240.6	369.0
1974	Berg, et.al.	103.1	25.3	226.6	355.0
1974	Ford Foundation	103.1	25.3	454.6	583.0
1975	Exxon	106.1	24.3	85.6	216.0
1975	Moody & Geiger	106.1	24.3	59.6	190.0
1975	Moody	106.1	24.3	66.6	197.0
1975	Miller, et.al.	106.1	24.3	75.6	206.0
1975	N.A.S.	106.1	24.3	80.6	211.0
1975	Shell	106.1	24.3	77.6	208.0

(Table 4.1 continued on next page)

(Table 4.1 continued from previous page)

1975	Rapp	106.1	24.3	39.6	170.0
1975	Rapp	106.1	24.3	32.6	163.0
1975	Rapp	106.1	24.3	24.6	155.0
1975	Bromberg	106.1	24.3	84.6	215.0
1975	Grossling	106.1	24.3	119.6	250.0
1976	Grossling	109.0	22.7	99.3	231.0
1976	Langston	109.0	22.7	71.3	203.0
1977	Fowler	111.9	20.1	22.0	154.0
1977	Fowler	111.9	20.1	48.0	180.0
1978	Tanner	114.7	19.5	44.8	179.0
1978	Tanner	114.7	19.5	31.8	166.0
1978	Shell	114.7	19.5	57.8	192.0
1979	Masters	117.8	17.8	71.4	207.0
1979	Hubbert	117.8	17.8	27.4	163.0
1979	Halbouty & Moody	117.8	17.8	57.4	193.0
1979	Parent	117.8	17.8	110.4	246.0
1978	Uri	114.7	19.5	63.8	198.0
1979	Uri	117.8	17.8	62.4	198.0
1981	Nehring	123.8	19.8	37.4	181.0
1981	Wiorkowski	123.8	19.8	32.4	176.0
1981	Mayer	123.8	19.8	21.4	165.0
1981	Mayer	123.8	19.8	21.4	165.0
1981	Mayer	123.8	19.8	46.4	190.0
1981	Dolton, et.al.	123.8	19.8	79.4	223.0
1981	Cargill	123.8	19.8	69.4	213.0

1) Estimator Abbreviations:
   OGJ = Oil and Gas Journal
   NPC = National Petroleum Council
   NAS = National Academy of Science
2) Data from American Petroleum Institute (1983)

TABLE 4.2: BIVARIATE REGRESSION OF MAGNITUDE OF PAST PRODUCTION, PROVEN RESERVES, AND UNKNOWN RESOURCES UPON DATE OF ESTIMATE.

DEPENDENT VARIABLE(1)	INDEPENDENT VARIABLE(2)	R^2	D.F.	F (3)		STANDARD ERROR
Past Production	Year	.9896	1/99	9424.	**	0.300
	Year + $Year^2$	.9998	1/98	5100.	**	0.044
Proven Reserves	Year	.2230	1/99	28.4	**	0.878
	Year + $Year^2$	.9020	1/98	679.	**	0.326
Unknown Resources	Year	.0596	1/99	6.27	*	9.480
	Year + $Year^2$	.3766	1/98	49.8	**	7.760

Note: All coefficients are maximum liklihood estimates computed with GLIM. An approximate R-square was estimated from the fitted model and the total scaled deviance.

1) Year = Date of publication - 1930
2) Ratio of scaled deviances divided by their degrees of freedom. The tests shown here are for increase in R-square. Linear models test null hypothesis that slope = 0. Curivilinear models test null hypothesis that semipartial = 0. Standard error calculated as the square root of the scaled deviance divided by its degrees of freedom.

* $p < .01$
** $p < .001$

respectively. Although the curvilinear model explains a statistically significant portion of the variance in past production, the increase attributable to the quadratic term is of minor substantive significance as the linear model accounts for fully 98 percent of the variance.

As noted in Chapter 2, the three component parts of the total estimate can be ordered in terms of the certainty about their magnitude. Past production, oil that has actually been removed from the ground, can be measured with extreme accuracy. Estimates of proven reserves are based upon highly technical formulae relating pressure, flow and other characteristics of oil that exists in the ground in pools delineated by successful wells drilled within a given distance of each other. As such, they are known with a reasonable assurance. Thus, data from a standard source (e.g. American Petroleum Institute, 1979:25; 1983:II-2) can be used to determine the values(1) and, as a result these two quantities can be treated as constant for all

---

(1) Proven reserve figures rarely differ by more than 10 percent (Ion, 1975). Thus, since proven reserves have never been much larger than 30 billion barrels, estimates of proven reserves from other sources would fall within 3 billion barrels of those used here. (See, for comparison, the series published annually in World Oil.) Although such differences have tremendous implications in policy debates over pricing and regulatory decisions (see Wildavsky and Tanenbaum, 1981), their magnitude is relatively inconsequential when compared with the differences among estimates of unknown resources.

estimates produced in a given year.(1) Thus, all of the variation among estimates produced in a given year can be traced to differences in the magnitude of the estimates of unknown, recoverable resources. This relationship is shown graphically in Figure 4.2 which compares the magnitude of the total estimate with the combined total of past production and proven reserves at the time the estimate was made. The distance between the trend line and the point estimate reflects the magnitude of the estimated portion of the total while the trend line captures the historical changes in the bases for the estimators current experience. Figure 4.3 graphically displays the relationships among the three constituent categories: past production, proven reserves and unknown recoverable resources.

Past Production, Proven Reserves and Current Experience

If the magnitude of the estimated portion of the total figure is affected by changes in the estimator's current experience, then chronological changes in the magnitude of past production and proven reserves should account for the

(1) The figures for a given year are as of the end of the previous year. Thus, they reflect the state of knowledge about the quantities at the time the estimate was made rather than the actual state of affairs at the time the estimate was made.

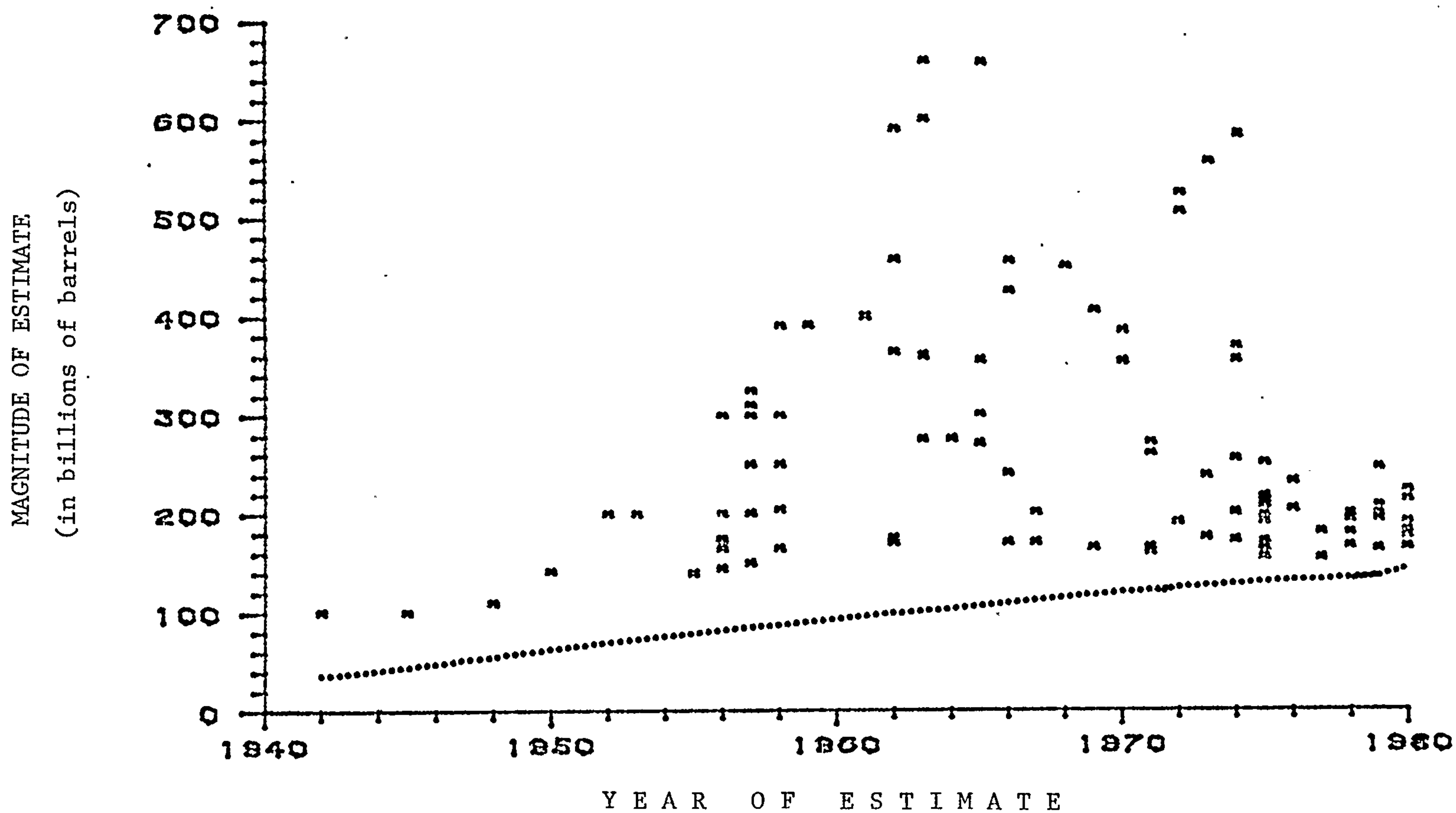


FIGURE 4.2: A COMPARISON OF THE MAGNITUDE OF ESTIMATES OF ULTIMATELY RECOVERABLE, CONVENTIONAL U.S. CRUDE OIL RESOURCES WITH THE MAGNITUDE OF PAST PRODUCTION AND PROVED RESERVES (COMBINED) AT THE TIME THE ESTIMATE WAS MADE.

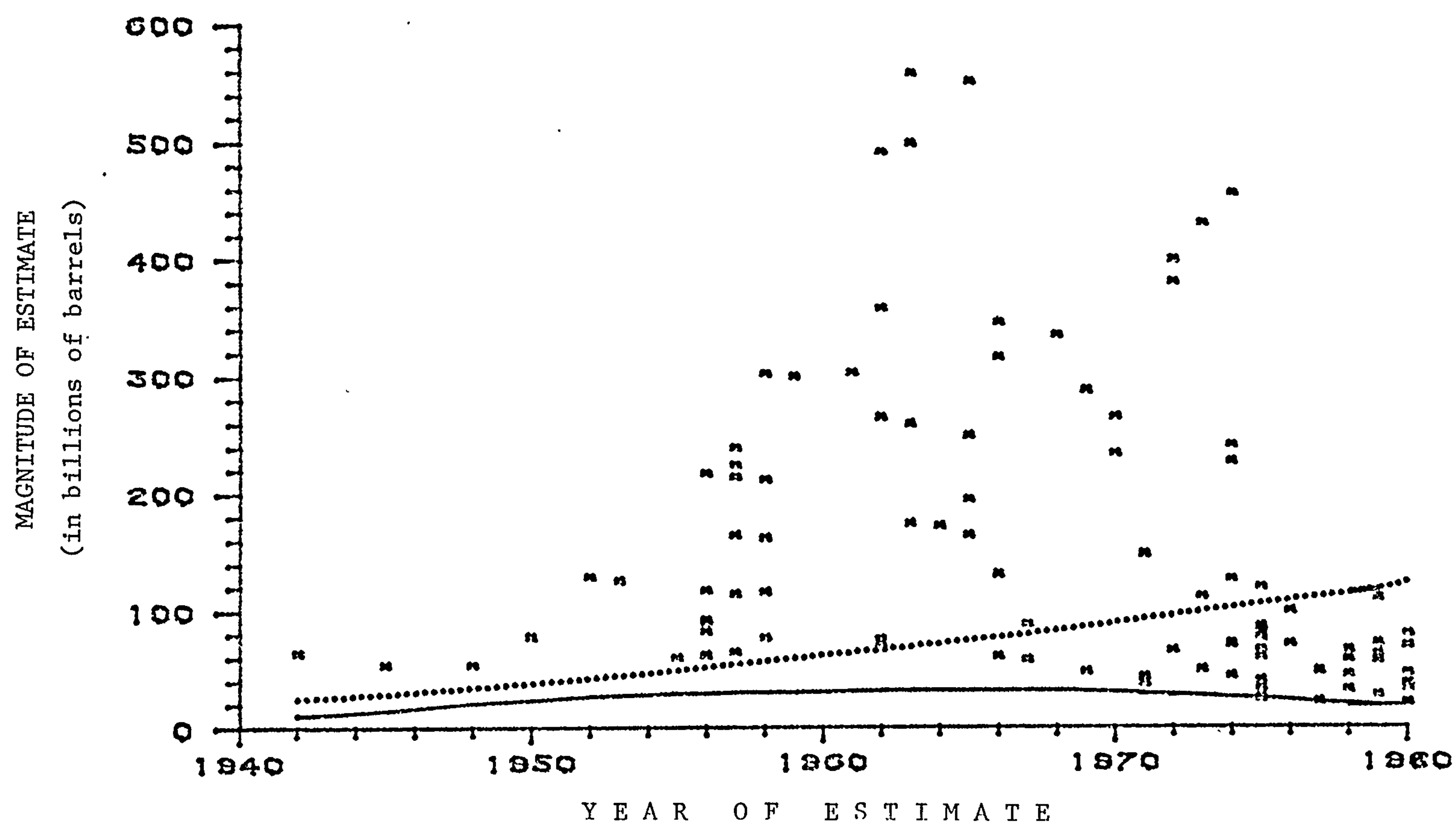


FIGURE 4.3: A SCATTERPLOT OF ESTIMATES OF UNKNOWN RECOVERABLE U.S. CRUDE OIL RESOURCES COMPARED WITH THE MAGNITUDE OF PAST PRODUCTION (DOTTED) AND PROVEN RESERVES (SOLID) AT THE TIME THE ESTIMATE WAS MADE.

chronological change in the mean magnitude of the estimates of unknown, recoverable resources. The models shown in Table 4.3 examine this question. The results confirm the expectation; utilizing past production and proven reserves to predict undiscovered resources accounts for approximately the same portion of the variance as explained by the time variable (i.e. 35 percent). More importantly, the portions of the variance explained are coextensive. Thus, the addition of the linear and quadratic terms associated with time yield insignificant increases in the variance explained (F-ratios of .91 and 4.86 at 1/97 and 1/96 degrees of freedom respectively). Similarly, by entering the terms in the reverse order it is possible to show that past production and proven reserves account for little of the variance beyond that associated with the linear and quadratic terms for time (an increase in the R-square from .3766 to .3788 yielding an insignificant F-ratio of .17 with 2/96 degrees of freedom).(1)

In sum, the two different sets of variables explain the same portion of variance in unknown recoverable

---

(1) Proven reserves have changed through time in a curvilinear manner while past production has changed in a linear manner. This explains why it is possible to express the curvilinear relationship of estimate magnitude with time as a linear function of past production and proven reserves.

TABLE 4.3: COEFFICIENTS OF DETERMINATION, F-RATIOS AND DEGREES OF FREEDOM FOR MODELS EXPLAINING THE MAGNITUDE OF ESTIMATES OF UNKNOWN US CRUDE OIL RESOURCES (NATURAL LOGS) ACROSS TIME.

INDEPENDENT VARIABLES	R^2	D.F.	F-RATIO
Past	.0796	1/99	8.56 *
Past + Prov	.3412	1/98	38.9 **
Past + Prov + Year	.3473	1/97	0.91
Past + Prov + Year + $Year^2$	.3788	1/96	4.86

Note: Contractions are as follows: Past, past production; Prov, proven reserves; Year, year of the estimate. The data for past production and proven reserves were taken from American Petroleum Institute (1983).

1) Year = Year of publication - 1930

2) F-ratio for the increase in R-square over the immediately preceding model. The tests shown here are for the null hypothesis that the semipartial correlation of the additional term = 0.

* $p < .01$

** $p < .001$

resources.(1) The concepts of past production and proven reserves, however, provide an insight into the causal dynamics that have resulted in the chronological changes in estimate magnitude. In addition, the coextensive nature of the two sets of variables lends credence to the suggestion that the magnitude of past production and proven reserves function as the criteria that estimators use to establish their perception of current experience.

The Meaning of Past Production and Proven Reserves

How do past production and proven reserves impact upon the perception of current experience? Past production can only increase with time. As it increases, however, the basis for conceptualizing the future of the oil industry changes. If one is operating in 1940 with a cumulative production of approximately 20 billion barrels since the beginning of the oil industry roughly 80 years earlier and an annual production rate of roughly one billion barrels, then the suggestion that there exist 50 billion barrels of undiscovered oil serves as a cause for reassurance. After

---

(1) Specifically, the common portion of the variance explained by the two sets of variables amounts to .3390 (the total explained variance of .3788 minus the two semipartials of .0376 and .0022) out of the total explained variance of .3788 or 89.5 percent of the total explained variance.

all, that is 2.5 times the amount produced in the last 80 years and an undiscovered supply of about 50 years at the current rate of usage. If, however, one is operating in 1970 with a cumulative production of approximately 100 billion barrels and an annual production rate of three billion barrels, then the suggestion that there exist 50 billion barrels of undiscovered oil serves as a cause for alarm. After all, that is an undiscovered supply of only 16 years at the current rate of usage. In other words, as cumulative production has risen, industry expectations about future demand have changed. As a result, conceptions about the need for future supplies have also changed.

Even as the quantitative expectations of future demand change, however, there is no need to fear the ability of the industry to respond to the increasing needs as long as the industry is finding petroleum at a more rapid rate than it is being used. Trends in the magnitude of proved reserves capture this aspect of industry behavior. If discoveries outpace production, then the magnitude of proved reserves will grow. If production outpaces discoveries, then the magnitude of proved reserves will fall. Thus, the trend in proved reserves provides a basis for assessing the continuing ability of the industry to meet future requirements.

If this reasoning is correct, then these conceptions should be evident in the discursive practices of estimators. The following selections are given as illustrations of historical interpretations that parallel those outlined above. No attempt has been made to systematically establish the proportion of the scientific community that shared these views at a given time.

The implications of both an increasing population and an increasing per capita demand for energy were noted by a variety of individuals throughout the period under examination. According to Weeks (1959:A-25): "population increase and an acceleration in per capita demand for energy . . . will produce a total demand for energy in the year 2059 of at least 40 and probably as much as 50 times that of 1959." Moody (1970:2239) raised the same issue in a more concrete manner:

> If we look at the total Free World energy requirements from now until 1990 and the part we feel conventional crude oil will play in meeting that demand, we see that the Free World will consume an estimated 500 billion bbl of crude oil during the next 20 years, or just about 80 percent of the estimated remaining Free World reserves. It is our best guess that, other things being equal, by 1990 the Free World will be producing at the rate of about 36 billion bbl/year. This rate is about 98 million bbl/day, and is 2 3/4 times current Free World production. If we further make the assumption that we would need a reserve-production ratio on the order of 10-15 to 1 to back up 1990 production, the Free World petroleum industry will have to add between 250 and 450 billion bbl of reserves between now and 1990 -- or about half as much oil as has been

> discovered since the birth of the modern petroleum industry 111 years ago. The challenge implicit in these numbers should be apparent to everyone (Moody, 1970:2239).

Although these individuals differed somewhat on the specifics of how much they expected future demand to increase(1) , our primary concern is with their assessments of whether or not U.S. resources would suffice to meet increasing U.S. demand.

The effect of changes in the proven reserve figures upon the answer to this question is illustrated in the following quote. Not only are estimates of ultimately recoverable resources tied to the trends in proven reserves, but the continued upward growth of those estimates is made contingent upon growth in proven reserves.

> Until such time as there is clear evidence that the domestic industry cannot find more than a barrel of oil for every barrel produced, there is no reason to believe predictions that we will soon be running out of oil. As more oil is discovered, the estimates of ultimate production in the United States will continue to be pushed upward and the predicted date of running out of oil will be forced further into the future (Gonzalez, 1957:49).

---

(1) For other assessments of future demand, see Hubbert (1956; 1962; 1974), Ayres (1955), or Schurr and Netschert (1960).

To summarize, the congruence of chronological changes in the magnitude of past production and proved reserves with chronological changes in the mean magnitude of the estimates of unknown recoverable resources can be explained if 1) the trends in proved reserves and past production impact upon the estimator's conceptualization of current experience and 2) estimators extrapolate their current experience into the future when making estimates of unknown resources. These conditions correspond to those outlined for the core assumptions account.

THE CAUSES OF DIFFERENTIAL INTERPRETATION

If the magnitude of past production and proven reserves serve as shared bases for establishing conceptions of current experience, what are the causes of differential extrapolation from that shared experience? At this point the core assumptions account interfaces with the two modes of explanation in the science studies literature. Do features internal to the practice of science explain the differential adoption of core assumptions that result in differing extrapolations or, alternatively, can the differential extrapolations be traced to features external to the practice of science? To answer these questions we must understand why the bases of current experience are not necessarily interpreted in the same manner by all estimators.

Beyond Geology

Changes in the rate of production or the magnitude of proven reserves are a function of industry behavior. Oil cannot be taken out of the ground or proved up without the investment of time and money by the industry. Such investments, however, are contingent upon a number of features. The factors bearing upon the movement from undiscovered to discovered resources, from discovered resources into proven reserves or vice versa, and from proven reserves into production can be classified into three basic categories: endogenous, exogenous and institutional (Congressional Research Service, 1978). The endogenous factors are those that are internal to the deposit. Thus, they include the physical, economic and technological factors that bear upon mining, refining and delivering the product to the marketplace (e.g. transportation, geographic factors that affect cost, various inputs into the production process like labor and energy, etc.). In sum, any factor that affects the ability of the specific petroleum occurrence to compete on either economic or technological grounds is included as an endogenous factor.

Even if a deposit is capable of competing in the marketplace, other factors may prevent its development. Primary among these are current and foreseeable economic conditions and the industry supply and demand situation. Companies are unwilling to undertake the conversion of a resource into a reserve unless they feel confident about the future. Finding and research costs are followed by expenditures for development, plants and equipment. Thus, funds are usually tied up for years between the time of discovery and that of production. As a result, research and exploration undertaken in a time of prosperity may not result in producible petroleum until a period of economic decline. Similarly, the current supply and demand situation and state of international relations play a major role in assessing whether or not to commit money to the development of particular deposit.

Perhaps even more important than such exogenous factors, however, are those known as institutional. These relate to governmental regulations and may extend to include health, safety and environmental rules, taxes, tariffs, subsidies, aid to other countries, and even treaty obligations. This group of factors is gaining increasing importance within the United States as the collective judgment of a small group of regulators is being substituted for the judgment of the market in order to facilitate the achievement of various social goals (Congressional Research Service, 1978).

Thus, the movement of resources between categories is a complex process involving factors related to economics, technology, and politics as well as geology. As a result, individuals can arrive at differential extrapolations from a shared current experience by interpreting that experience differentially. For example, one estimator may take a decline in the proven reserve figures from one year to the next as an indication of physical shortage; the oil could not be proved up because it is becoming exhausted and, hence, harder to find. Another estimator, however, may attribute the same decline in the proven reserves figures to the economics of the present situation; the oil was not proved up because exploration costs in the U.S. are higher than in another area and, hence, the industry did not invest the money required to prove up the existing U.S. oil.(1)

---

(1) For an historical example of such differences, compare Hubbert (1967; 1974) with National Petroleum Council (1971). Hubbert treats the decline in discoveries as indicative of physical shortage while the National Petroleum Council traces the decline to a lack of adequate exploration incentives.

Internal versus External Factors

If this explanation is valid, i.e. if it is to explain the changes in consensus about the mean magnitude of the estimates, then there should exist an interaction effect between some aspect of the estimators current experience (e.g. either past production or proven reserves) and at least one of the characteristics associated with either the estimate or the estimator. The type of interaction effect one expects, however, depends upon the explanatory scheme being used. Attribution theory would expect the interaction to occur between factors internal to the practice of science and the bases of current experience. Alternatively, interest theory would predict an interaction between factors external to the practice of science and the bases of current experience. Equally as important, interest theory holds that external factors impact upon the practice of science. Thus, like attribution theory, interest theory predicts significant direct effects associated with the internal features of scientific practice. Interest theory differs, however, in its suggestion of a relation between internal and external factors and, hence, the expectation that internal factors provide a vehicle for the indirect effects of external factors.

Table 4.4 contains coefficients of determination and F-tests for a variety of models predicting the magnitude of estimates of unknown U.S. crude oil resources. The addition of each new term within the hierarchical set of models adds significantly (at $p < .001$) to the proportion of variance explained. Method, as would be expected by either an attribution or an interest explanation of the phenomenon, accounts for a considerable proportion of the variance (roughly 20 percent). The addition of organization and the associated interaction of organization with proven reserves yields an increment of nearly 25 percent in the explained variance. Although this finding does not necessarily contradict the attributional explanation, it clearly harmonizes with the interest account.

The existence of a significant interaction between organization and proven reserves implies that the organization effect varies across organizations depending upon the magnitude of proven reserves. Thus, given that the magnitude of proven reserves impacts upon an estimator's conceptualization of future trends (see the previous section of this chapter), the manner in which this occurs, while consistent for organizations of a single type at a given time (i.e. at a specific value of proven reserves), 1) differs across organizations and 2) differs

TABLE 4.4: COEFFICIENTS OF DETERMINATION, F-RATIOS AND DEGREES OF FREEDOM FOR MODELS PREDICTING THE MAGNITUDE OF ESTIMATES OF UNKNOWN U.S. CRUDE OIL RESOURCES.

INDEPENDENT VARIABLES	R^2	D.F.	F-RATIO
Past	.0698	1/99	7.42 *
Past + Prov	.2492	1/98	23.4 **
Past + Prov + Meth	.4544	3/95	11.9 **
Past + Prov + Meth + Org	.6091	3/92	12.1 **
Past + Prov + Meth + Org + (Org x Prov)	.6902	3/89	7.7 **

Note: Contractions are as follows: Past, past production; Prov, proven reserves; Method, estimation methodology; Org, employing organization; (Org x Prov), interaction of organization with proven reserves. The data for past production and proven reserves were taken from American Petroleum Institute (1983). The coefficients of determination for Past and Prov do not equal those in Table 4.3 due to several technical differences; the models in this table assume normally distributed error terms and were run using ordinary least squares regression.

1) F-ratio for the increase in R-square over the immediately preceding model. The tests shown here are for the null hypothesis that the semipartial correlation of the additional term = 0.

* $p < .02$

** $p < .001$

within organizational type across values of proven reserves and, hence, across time. One explanation for such a phenomena would be that organizations create a culture or discursive environment in which certain meanings are attributed to the changes in the proven reserve figures but that 1) these cultures or discursive environments differ across organizations and 2) the meaning attributed to the trend by at least some of the organizations changes through time.

Direct Effects

To understand the manner in which this process was historically enacted one must examine the effect parameters of the models (see Table 4.5). In the main effects model both organization and time account for a significant proportion of the variance around the change in mean magnitude explained by the trends in the past production and proven reserve figures. The effect parameters for method show that geological analogy and volumetric yield estimates have been significantly larger (by an average of 47.9 and 73.7 billion barrels respectively) than those produced by field size and other methods. Similarly, independent and government estimators have produced estimates that are significantly larger (by an average of

TABLE 4.5: EFFECT PARAMETERS FOR THE MAIN EFFECTS AND INTERACTION MODELS PREDICTING THE MAGNITUDE OF ESTIMATES OF UNKNOWN U.S. CRUDE OIL RESOURCES (FIGURE 4.1; TABLE 4.4).

INDEPENDENT VARIABLES	MAIN EFFECTS MODEL BETA	MAIN EFFECTS MODEL B		INTERACTION MODEL B	
Proven	.47347	12.3101	**	4.1751	
Past	-.03018	-.1484		.4103	
Method (c)					
Exp. Hist.	-.03704	-10.2552		2.2215	
Geol. Anal.	.16799	47.9214	*	41.0012	*
Vol. Yield	.26373	73.6992	**	76.3219	**
Organization (c)					
Industry	.15518	39.7887		-35.6565	
Independent	.34947	111.9794	**	-394.9170	**
Government	.59732	176.7334	**	-353.3446	**
Interactions (c)					
Industry x Prov				2.9586	
Independent x Prov				19.4818	**
Government x Prov				19.0812	**
Constant		-279.2674		-103.4848	

Note: Method and organization are categorical variables. Their coefficients are interpreted as deviations from the mean of the excluded category (Field-size/Other in the case of method and Hubbert in the case of organization) Similarly, the interaction coefficients are interpreted as deviations from the slope of proven reserves.

* Effect greater than or equal to 1.65 times the standard error.

** Effect greater than or equal to twice the standard error.

112 and 177 billion barrels respectively) than those produced by Hubbert. Industry estimates, although not significantly larger, have been greater than Hubbert's by an average of 40 billion barrels.

The relative explanatory importance of organization and methodology is not immediately apparent from an examination of the effect parameters. This problem arises as a result of the nominal nature of the variables and, hence, the existence of different effect parameters for each category rather than a single parameter associated with the variable as a whole. A technique developed by Heise (1972), however, provides a means to address this question; it provides a single coefficient that summarizes the causal effects of a set of variables when other variables are controlled. This technique involves 1) recasting the relations into a form similar to that in Figure 4.4, where x (i.e. organization or method) stands for an unmeasured set of numerical values (chosen so that each value corresponds to one category) while the set as a whole relates linearly to estimate magnitude (z) and 2) assuming that the set of indicators (w) perfectly define the unmeasured construct. This allows the calculation of a "scheaf coefficient" (p) indicative of the direct effect of the nominal variable upon the dependent variable while controlling for the other variables in the model. Tables

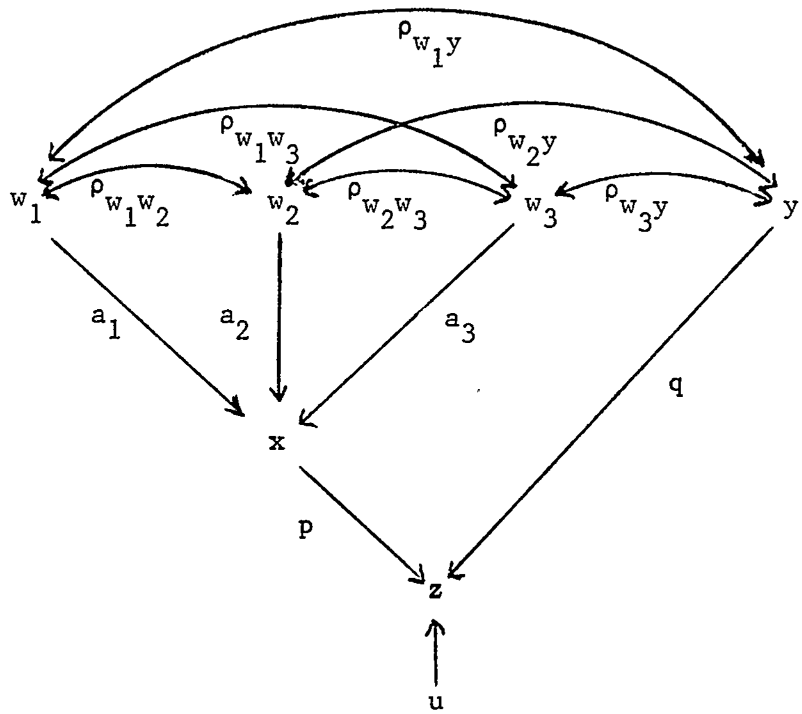


FIGURE 4.4: RELATIONSHIP AMONG VARIABLES INVOLVED IN THE CALCULATION OF THE SCHEAF COEFFICIENT (FROM HEISE, 1972)

TABLE 4.6: SHEAF COEFFICIENT (P) FOR THE DIRECT EFFECT OF METHOD UPON MAGNITUDE OF UNKNOWN RESOURCES (ADDITIVE MODEL).

CORRELATION MATRIX

(W1)	1.00000		
(W2)	-.41214	1.00000	
(W3)	-.43258	-.40258	1.00000
	(W1)	(W2)	(W3)

A1= -.1240 A2= .5622 A3= .8826

P= .2988

Note: W1=Exp. Hist.; W2=Geol. Anal.; W3=Vol. Yield
For interpretation of other symbols, see Figure 4.4

TABLE 4.7: SHEAF COEFFICIENT (P) FOR THE DIRECT EFFECT OF ORGANIZATION UPON MAGNITUDE OF UNKNOWN RESOURCES (ADDITIVE MODEL).

CORRELATION MATRIX

(W1)	1.00000		
(W2)	-.45443	1.00000	
(W3)	-.52453	-.28499	1.00000
	(W1)	(W2)	(W3)

A1= .1997 A2= .4498 A3= .7688

P= .7770

Note: W1=Industry; W2=Independents; W3=Government
For interpretation of other symbols, see Figure 4.4

4.6 and 4.7 display the scheaf coefficient and other relevant parametric measures associated with the direct effects of method and organization respectively. A comparison of the scheaf coefficients, interpretable as standardized regression coefficients, shows that the direct effect of organization (p = .7769) is more than twice the direct effect of method (p = .2988).

The main effect for organization becomes uninterpretable in the interaction model due to its conflation with the interaction between organization and proven reserves (see Table 4.5).(1) The effect parameters show significant interaction between both government and independent estimates and proven reserves (deviations from the base category slope of approximately 19 in each case). Thus, the slopes of the various types of organization upon proven reserves are approximately 4 for Hubbert, 7 for industry estimates, and 23 for both independent and government estimates. This indicates that changes in the proven reserve figures had a dramatic effect upon both independent and government estimates. During the period that proven reserves were increasing (i.e. up until the

---

(1) As a result of the interaction terms the standardized regression coefficients for the organization effects become meaningless and, hence, the scheaf coefficient also becomes uninterpretable. Thus, it is not possible to compare the relative importance of organization and method in the interaction model.

mid-1960's), both government and independent estimates of unknown recoverable resources increased at a rate of approximately 23 billion barrels for each additional billion barrels of oil the industry was able to prove up. Since the late 1960's and the concomitant decline in proven reserves, the magnitude of government and independent estimates has fallen at the same rate. By way of contrast, the effect of changes in the magnitude of proven reserves has been relatively minor for both Hubbert and industry estimators.(1)

These differences are shown graphically in Figures 4.5 to 4.8 through a display of the predicted values from the interaction model in Table 4.5 given the actual historical status of past production and proven reserves for each year. Each figure plots the magnitude of the estimates predicted for a given organization depending upon the current experience with which the estimator was working and the variation around that value depending upon the type of estimation methodology utilized. Figure 4.5 displays the predicted values for industry estimators while Figures 4.6,

---

(1) Hubbert (1962; 1965; 1966) has repeatedly downplayed the utility of using the trend in proven reserves as index of the industry's ability to meet future demand in favor of an analysis of trends in the discovery rate. Thus, Hubbert's estimates did not interact with changes in the magnitude of proven reserves because he explicitely avoided using this criteria as a basis for establishing his perception of future trends.

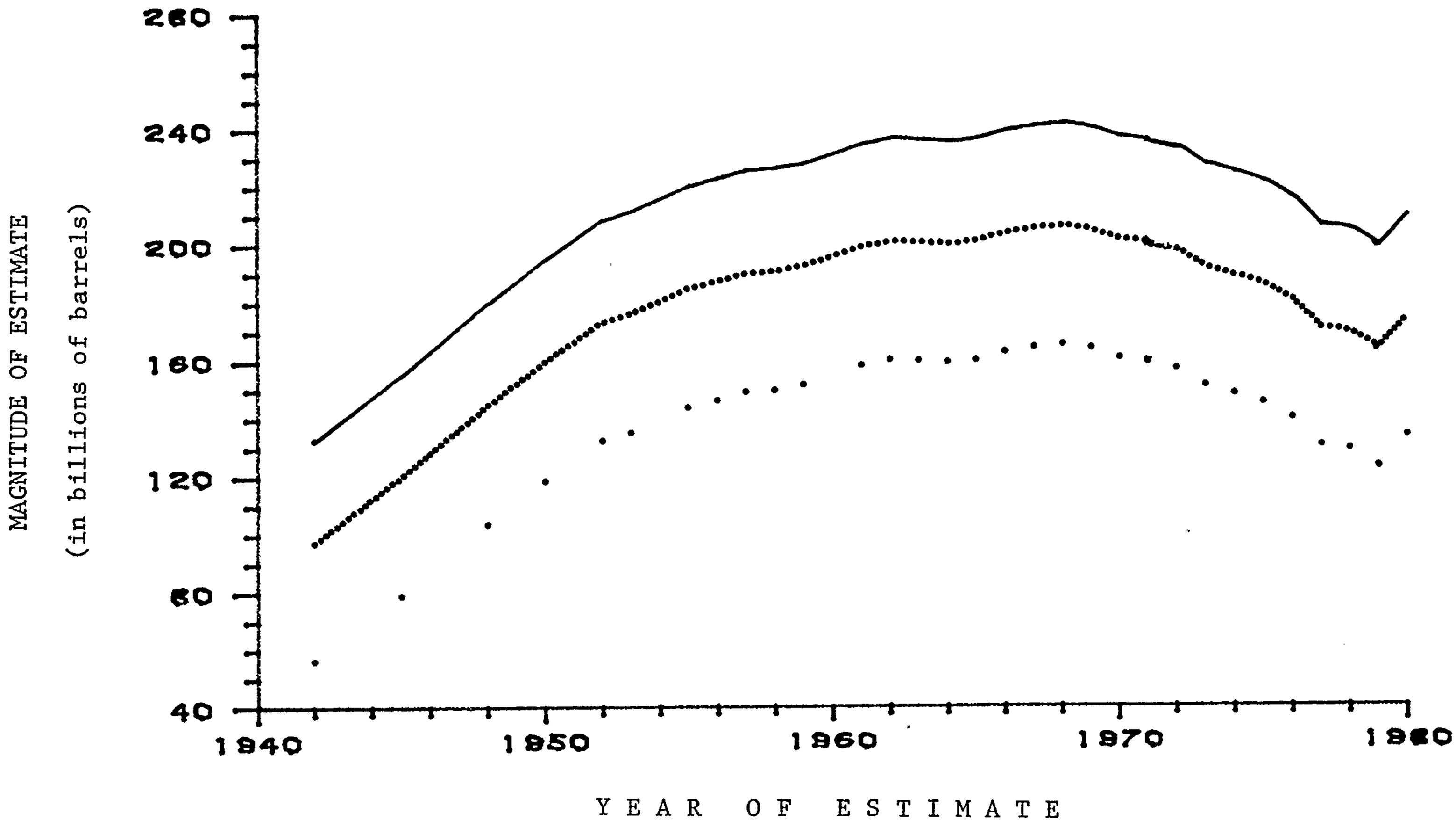


FIGURE 4.5: PREDICTED VALUES FOR ESTIMATES PRODUCED BY INDUSTRY ESTIMATORS

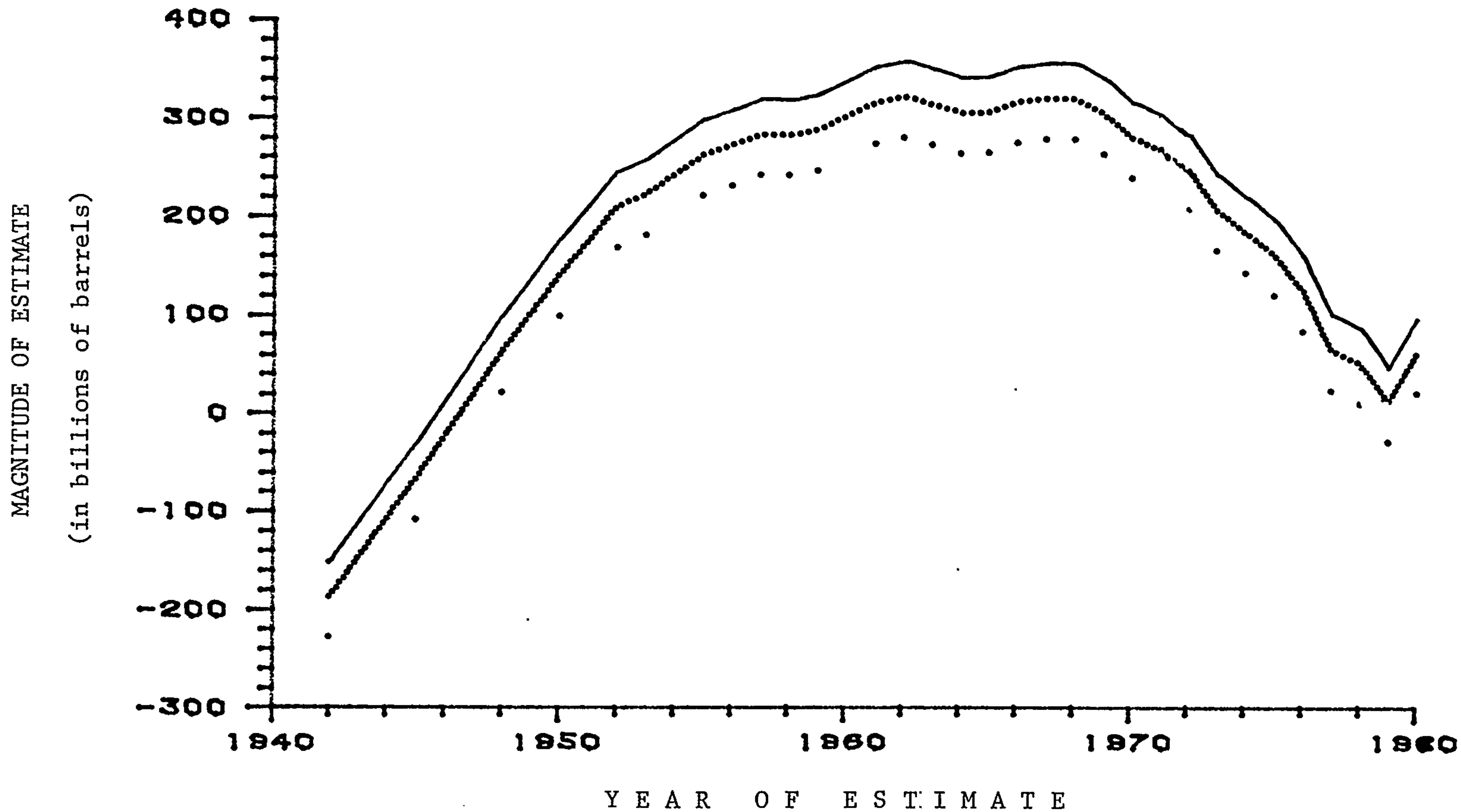


FIGURE 4.6: PREDICTED VALUES FOR ESTIMATES PRODUCED BY INDEPENDENT ESTIMATORS

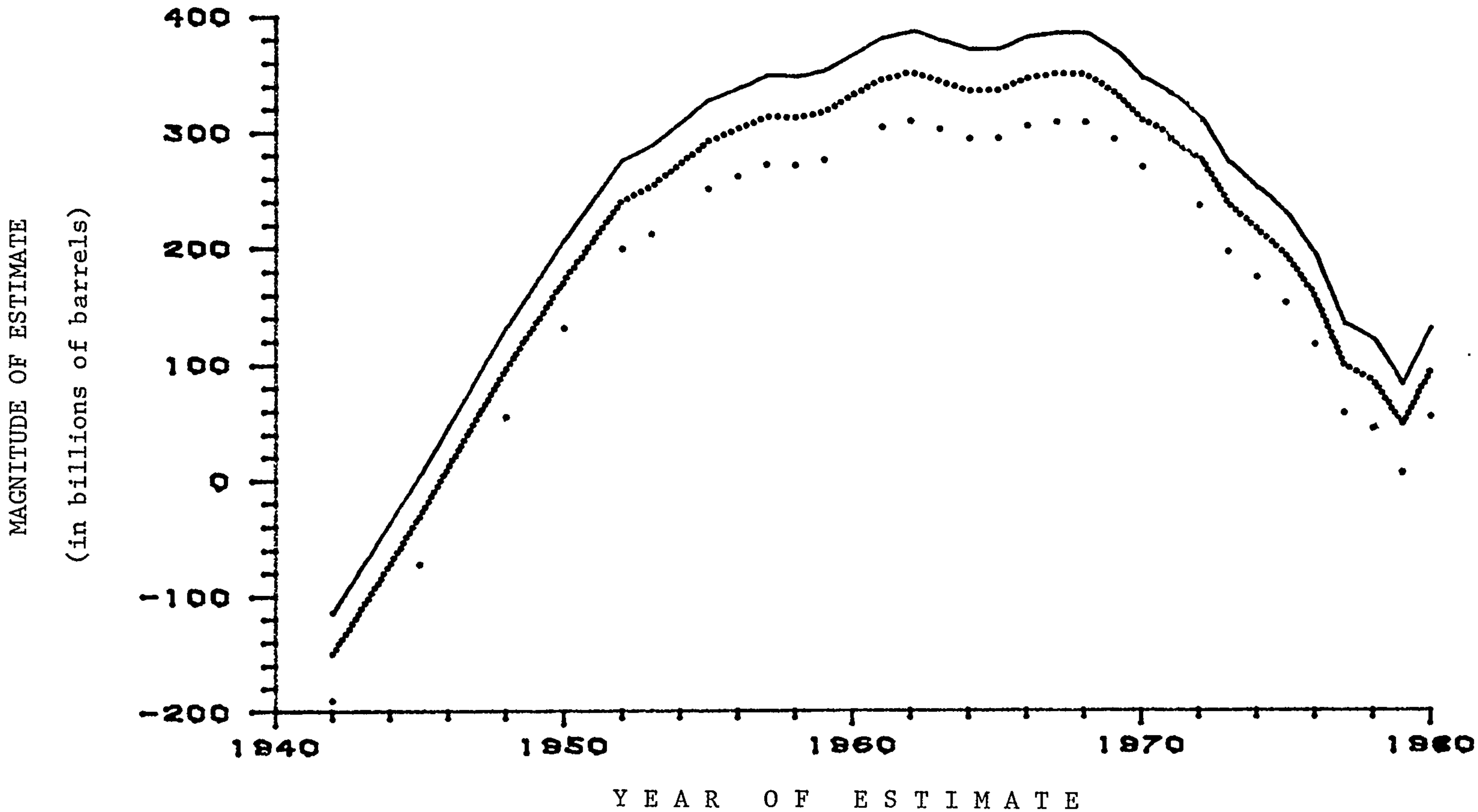


FIGURE 4.7: PREDICTED VALUES FOR ESTIMATES PRODUCED BY GOVERNMENT ESTIMATORS

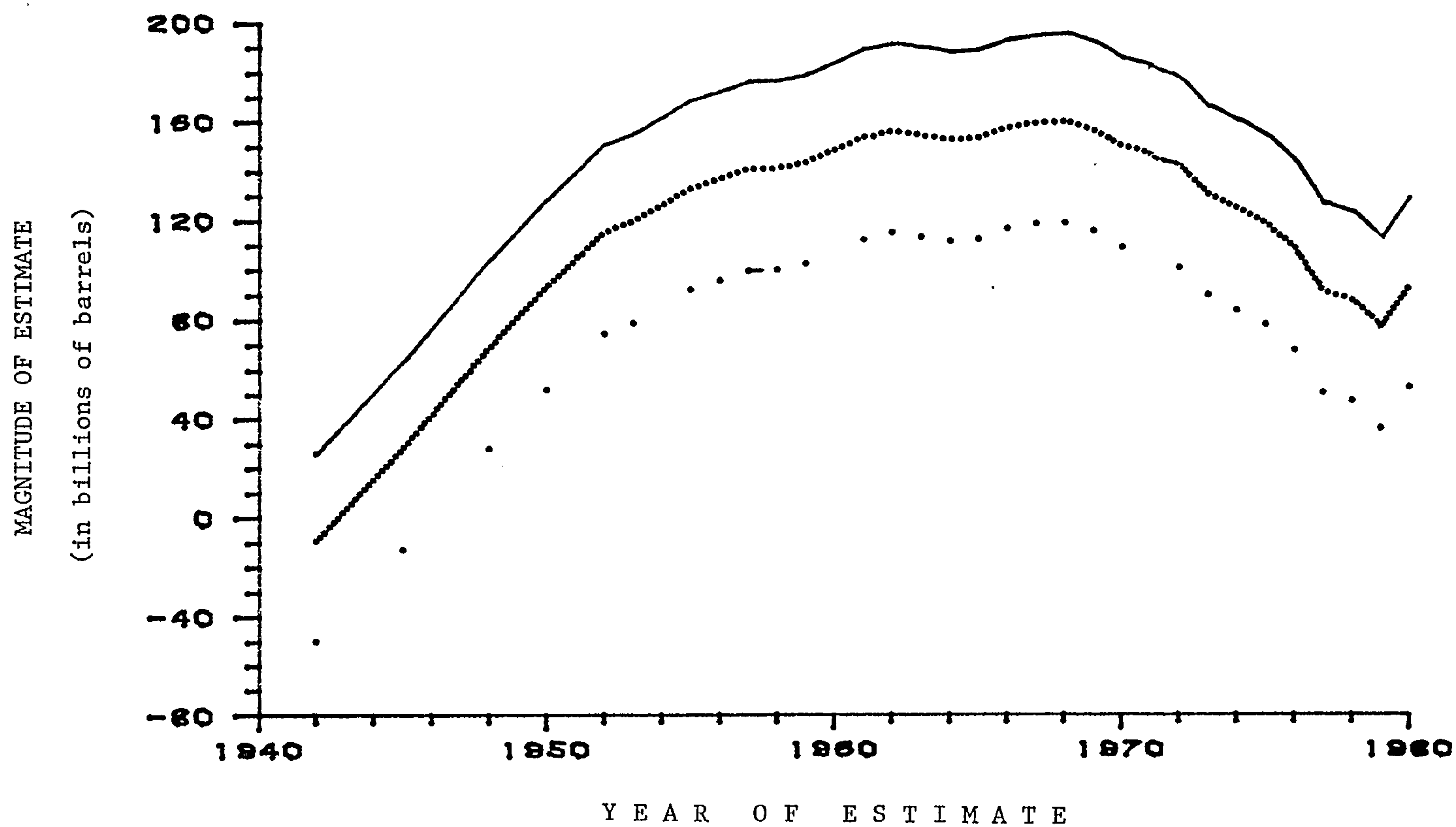


FIGURE 4.8: PREDICTED VALUES FOR ESTIMATES PRODUCED BY HUBBERT

4.7, and 4.8 display the predicted values for independent and government estimators and Hubbert respectively. The different lines in each figure represent the predicted values associated with the various estimation methodologies. Field-size, exploitation history and other methods are represented by points while geological analogy and volumetric yield estimates are represented by the dotted and solid lines respectively.(1)

Indirect Effects

The preceding analysis has been concerned with the direct effects of a variety of variables upon estimate magnitude. A further question arises as to the nature of the relationship between organization and method. Does there exist an indirect effect of organization upon estimate magnitude through the intervening variable of method? This would only occur if there existed a significant effect of organization upon method. Stated in substantive terms, does employment in a particular organizational type impact upon the selection of estimation methodology?

---

(1) The plots of predicted values have been truncated so that the time span covered conforms to the period for which estimates were actually produced by individuals within that organizational type.

Logit models can be used to address such questions when the variables involved are categorical (Swafford, 1980). In essence, logit models assess the extent to which an independent variable (e.g. organization) affects the probability of falling into one category as opposed to another of the dependent variable (e.g. methodology). The models in Table 4.8 test the null hypothesis that the log-odds of utilizing a particular estimation methodology does not vary across organizational type.(1)

Significant results obtain for two of the four estimation methodologies. Thus, while it is not possible to make a generalization about the effect of organization on methodology that subsumes all four methods, there does exist a significant effect of organization upon method for certain methods (i.e. geological analogy and volumetric yield). In these cases the average effect of organization upon the log-odds of selecting that methodology are -.5916 and .5843 for the geological analogy and volumetric yield methodologies respectively. Examination of the frequency distribution shows that government estimators make disproportionate use of the volumetric yield method (i.e.

---

(1) Technically logit models utilize the natural logarithm of the odds of falling into category one rather than category two (where category two includes all occurrences that are not in category one) as their criterion variable.

TABLE 4.8: FREQUENCY DISTRIBUTION, COEFFICIENTS OF DETERMINATION AND EFFECT PARAMETERS FOR LOGIT MODELS OF ORGANIZATIONAL TYPE UPON ESTIMATION METHODOLOGY.

ORGANIZATION	FREQUENCY DISTRIBUTION E.H.	G.A.	V.Y.	O.	TOTAL
Industry	9%	50%	24%	17%	100 (46)
Independent	60	15	10	15	100 (20)
Government	28	4	68	0	100 (25)
Hubbert	80	10	0	10	100 (10)

METHODOLOGY	R^2	B (1)	S.E.
Exploitation History	.0168	.1086	.1508
Geological Analogy	.4926	-.5916 *	.1907
Volumetric Yield	.4819	.5843 *	.1682
Field-size/Other	.8673	-.1850	.1377

Note: All coefficients are maximum liklihood estimates calculated under the assumption that the error structure takes a binomial distribution. GLIM was used to compute these estimates. An approximate R-square was calculated from the scaled deviance for the fitted model and total scaled deviance. Symbol are used as follows: S.E., standard error of the estimate; E.H., exploitation history; G.A., geological analogy; V.Y., volumetric yield; O., field-size/other.

1) Significance (*) based upon an effect more than twice the size of the standard error.

they account for 68 percent of the government estimates as against 25 percent or less for other organizations) and that industry estimators make disproportionate use of the geological analogy method (i.e. they account for 50 percent of the industry estimates as against 25 percent or less for other organizations).

It should be noted that these two methodologies yield significantly larger results than the other estimation methodologies (see the effect parameters for the various methods in Table 4.5). Thus, although there is not a generalized indirect effect of organization upon estimation magnitude that occurs through methodology for every type of methodology, when an indirect effect does occur it has a substantial impact upon the estimate magnitude.

CONCLUSIONS

The historical pattern of estimates of unknown, recoverable U.S. crude oil resources can be understood as a function of two sets of variables. The first set of variables, i.e. the magnitude of past production and proven reserves, reflect aspects of the estimator's knowledge base that affect their extrapolation and account for the change in the mean magnitude of the estimates through time. The second set of variables, i.e.

estimation methodology, organization of employment and the interaction between the variables within the two sets, accounts for the variation around the mean magnitude of the estimate. Thus, the theoretical model displayed in Figure 4.1 directly explicates two of the three features of the historical pattern. The major difference between the predicted values from that model and the historical pattern lies in the breaks between periods; the historical pattern consists of discrete periods while the model predicts a process of continuous transformation and, hence, does not account for the existence of discrete periods. Chapter 5 examines the relationship between exogenous and institutional factors and the existence and timing of the breaks between periods.

CHAPTER 5

ORGANIZATIONAL INTERESTS, POLITICAL ECONOMY AND HISTORICAL CHANGE

The preceding chapter detailed a process that accounts for the chronological changes in both the mean magnitude of the estimates of unknown resources and the changes in variation around that mean. This chapter extends the analysis by linking that process to changes in the political economic environment of the international oil and gas industry. It will be shown that changes in that context account for 1) the existence of specifiable periods and 2) the timing of the breaks between periods. Thus, this chapter explains how a continuous process has given rise to a discrete pattern.

The chapter begins with a brief examination of the historical development of the structure of the political economic environment of the U.S. based oil industry. That context has been characterized by a constant set of organizational types throughout the period 1940 to 1981. The second section examines the network of relations among these organizational types and specifies, at a structural level, organizational interests that have remained constant throughout the period under examination. The third section chronicles historical changes within the dynamics and dependencies of the interorganizational network that explain the nature and timing of the breaks between periods.

THE STRUCTURE OF THE OIL INDUSTRY

The United States oil industry underwent a major change at the turn of the century. Prior to 1900 the industry was monopolistic; Standard Oil produced 90 percent of all U.S. oil in 1880. Between 1900 and 1911 half a dozen new integrated firms entered the marketplace reducing Standard Oil's share of the market to approximately 60 percent. The new companies accomplished this by seizing new market opportunities(1) and responding to the shift toward production from the mid-Continent and Gulf regions (Williamson and Andreano, 1960:71-84; Hidy and Hidy, 1955:573-579; Kolko, 1963:39-42). The oil market was changing from the "Age of Illumination" to the "Age of

---

(1) The new companies produced 70 percent of U.S. fuel oil, 45 percent of the lubricants and 35 percent of the gasoline (Nash, 1967:8).

Energy" and Standard Oil was not able to maintain its market domination.(1)

In 1911, the United States Supreme Court brought down a landmark ruling requiring the break up of the Standard Oil monopoly. This decision hastened the transition to oligopoly started by the market changes. Additionally, the decision allowed the U.S. government to replace a primarily negative policy toward the oil industry (i.e. one based upon laws designed to prevent undue concentration of economic wealth and power) with a more positive policy based upon regulation and supervision of industry activities (Nash, 1967:1-22,238-240).

Thus, the turn of the century saw three interrelated shifts in the political economic structure of the United States oil industry; the first in the market, the second in the industry and the third in government policy toward the industry. These changes were brought about by the increased demand for oil which accompanied the American industrial experience. Especially striking was the increase in fuel oil consumption that accompanied the conversion of railroads and ships from coal to oil and the emergence of the automobile as a means of private

---

(1) See Williamson, et. al., 1959-1963 or Schurr and Netschert, 1960:84-100; for extensive documentation of this transition.

transportation.(1) In order to provide for this rapidly increasing demand, the oil industry implemented a variety of production techniques that emphasized immediate production and resulted in excessive waste (Williamson, et. al., 1963:44-49; Ise, 1926:416-420).

In this context of massively increasing demand and excessive waste the United States Navy considered conversion to petroleum. Although evidence of the superiority of oil burning ships was overwhelming and the British were well on the way to conversion, U.S. Naval authorities were hesitant to convert (DeNovo, 1955:641-646). The main reason was a concern about the long range availability of petroleum.(2) Although the Navy had raised the issue of an adequate petroleum supply, the United States government made no attempt to facilitate American oil companies getting concessions in foreign

---

(1) Fuel oil consumption rose from 12 million barrels in 1899 to 224 million barrels in 1919 while vehicle registrations rose from 8,000 to 7.6 million in the same period (Nash, 1967:6).

(2) President Taft, acting on a suggestion from Secretary of the Interior Ballenger, removed certain public lands from disposition in 1909 and, in 1912, created the Naval Petroleum Reserves at Elk Hills and Buena Vista Hills, California. The third Naval reserve, the infamous Teapot Dome, was added in 1915. After these measures were taken and the Secretary of Interior assured the Navy of the country's ability to meet their fuel needs, the Navy committed itself to oil burning ships (DeNovo, 1955:646-648).

countries. Instead American policy tended toward conservation and laying aside of emergency reserves. This is in marked contrast to the policy followed by the British. Britain, lacking adequate petroleum within her empire, actively sought concessions throughout the world (particularly in the Middle East).

World War I drastically altered U.S. apathy toward foreign sources of petroleum. Three major factors account for this rapid change in orientation: 1) the war demonstrated the role of petroleum in national defense; 2) new reports emphasized the future inadequacy of U.S. petroleum resources, and 3) the nation became aware of Britain's active attempts to gain control of Middle East oil (DeNovo, 1956:856-7). A temporary unification of public and private policy resulted; the U.S. oil industry was given both government and public support for its pursuit of financial gain in foreign countries. Thus, by the mid-1920's the political economic environment of the U.S. oil industry was international in scope; it involved not only the oil companies and their home governments, but also the governments of the oil exporting less-developed countries.(1)

NETWORK RELATIONS AND ORGANIZATIONAL INTERESTS

Network Relations

The preceding section documented the emergence of a particular structure for the U.S. oil industry and its transnational corporate actors. But how are these actors related to each other? To answer this question one must specify both the level and the dimensions of the organizational environment and the nature of the relations between the organizational actors (Scott, 1981:164-74). As noted by Perrow (1979:217-18), however, the levels of organizational environment are not entirely distinct; they interrelate like nested boxes.

> (I)nside each box is a smaller box whose dimensions are constrained by the larger box.

---

(1) A complete accounting of the structural actors involved in the dynamics of the international oil industry would include a number of other types; industrialized oil importers (e.g. Japan), oil importing less-developed countries and sporadic superpower exporters (i.e. the Soviet Union). For recent treatments of the roles of these actors see Vernon (1983), Smil and Knowland (eds) (1980), and Stern (1982) repectively. These actors have not been excluded from the analysis because their roles are unimportant but, rather, because their actions are not central to an understanding of changes in U.S. resource estimates.

> Each box is independent to some extent of the large boxes (and the smaller ones within it), and can be analyzed as such. But it is also quite dependent upon the shape of those within and without it.

This chapter concerns itself with the relationship between interorganizational fields(1) at two different levels of analysis. Specifically, it involves analysis of how the changes in the network relations within a world system (i.e. the political economy of the international oil industry) influence perceptions of individuals working within a national set of organizational relations (i.e. the relations among the various groups producing the estimates). The connection between the two levels follows from the structural situation of the U.S. based transnational oil corporations; they dominate both the national and international industries and, on the international level, act as a buffer between the U.S. government and the governments of the less developed oil exporting countries.(2)

The transnationals do not, however, act as buffers across the entire spectrum of international relations. The

---

(1) Warren (1967) uses this term to refer to the relations among a set of actors within a specified geographical area.

(2) See Scott (1981:188-93,244-5) for a generic treatment of organizations as buffers. See Turner (1983:118-21) for an examination of the buffer role played by U.S. based transnational oil companies.

U.S. government, for example, has political, military and strategic interests in the Middle East (Turner, 1983:103-10) that are frequently irrelevant to the economic role of the transnational corporation (Turner, 1983:121-24).(1) The buffer role of the transnational corporation can be identified as "political-economic" (Zald, 1970) or as involving questions of "resource dependency" (Pfeffer and Salancik, 1978). According to Scott (1981:169), there exist three dimensions affecting such dependencies: 1) the degree of munificence - scarcity (i.e. the extent to which the resources needed by an industry are available in the organizational environment), 2) the degree of concentration - dispersion (i.e. the extent to which the resources are evenly distributed throughout the organizational environment) and 3) the degree of organization - nonorganization (i.e. the extent to which an organization confronts a set of actors whose actions are structured and coordinated).

Due to the geology of petroleum occurrence, the vast majority of oil is located in a small number of extremely large pools existing in a small number of locales. This

---

(1) Although it has frequently been suggested that these differing interests are not separable (e.g. U.S. corporate domination over Middle East oil has been achieved and maintained through gunboat diplomacy), a nonpolemical assessment of the evidence does not justify such claims (Turner, 1983:68-98).

fact has facilitated a high degree of concentration in the organizational environment; oil is controlled by a small number of organizational actors. This aspect of the dependence relations has not changed substantially since 1940. As will be chronicled in the third section of this chapter, the other two dimensions have changed dramatically since that time. For present purposes munificence - scarcity has been operationalized in terms of the historically extant supply and demand situation. The degree of organization - nonorganization has been operationalized as the degree of coordination among the actions of the less-developed oil exporting countries. In general, it will be argued that changes in these dependence relations have influenced the production of U.S. petroleum resource estimates. Before examining this question, however, it is necessary to understand the particular interests with which the various organizational actors have operated.

Organizational Interests

The following analytic framework, drawn from Tanzer (1969:20-9), specifies the structural interests of the relevant organizational types within the political economy of the international oil industry.

U.S. oil companies can be classified into four categories on the basis of differentiation along two dimensions: vertically integrated versus nonintegrated firms and internationally versus domestically active firms. All these companies share the basic aim of profit maximization, but there exist important differences among them. Integrated firms (i.e. those that possess production, refining, distribution and marketing facilities) collectively dominate access to the world's low cost oil resources. Nonintegrated firms, both domestic and international, have had considerable success finding low cost oil but, due to a lack of refining and marketing facilities, have been unable to gracefully fit this oil into the world market. More importantly, integrated firms can utilize internal paper transactions to shift profits from one division to another, a convenience not available to nonintegrated firms. As a result, nonintegrated firms have traditionally maximized short-term rather than long-term profits. Similarly, internationally active firms can draw profits from both the domestic and the international arms of the firm, a luxury not available to firms operating solely within the U.S. These differences in market interest frequently lead to policy differences within the oil industry.

The United States serves as the headquarters for most of the international oil industry.(1) The specific interests of the U.S. government are: 1) to ensure the availability of energy supply, 2) to minimize the negative impact or maximize the positive impact of oil on the international balance of payments and 3) to provide support for international oil companies with headquarters within the country.

The major role of the oil exporting less-developed countries involves placing pressure on the international oil companies for larger and larger shares of the oil revenues. Several factors have traditionally militated against the nationalization of international oil company property: 1) no single oil exporting country dominates the international oil trade, 2) each of the majors can obtain large quantities of oil from more than one of the exporting countries, 3) the oil sector of the economy has traditionally been isolated from the rest of the exporting country's economy (although this has changed considerably in the last decade) and 4) the oil exporting governments are either directly or indirectly dependent upon the

---

(1) Of the seven largest players in the international industry, five of them are based in the U.S. (Exxon, Mobil, Standard Oil of California, Texaco, Gulf). The other two (British Petroleum, Shell) are under British and British/Dutch control respectively.

Western nations for maintaining their power. Short of nationalization, the exporting countries have attempted to increase their take from the oil revenues by pressuring for increased production, higher prices, a greater share of the revenues and increased participation in the industry by indigenous corporations. In the past decade, however, changes have allowed these countries to increase the direct control they exercise over indigenous resources.

DEPENDENCE RELATIONS AND HISTORICAL CHANGE

The preceding section suggested that resource estimates of very large areas (e.g. a country, the world) are produced by organizations working within a national set of network relations constrained by the political economy of the resource industry at the international level. Equally as important, these political economic relations define the market interests of the various organizational actors. These interests (strategic goals), however, can be pursued through a variety of different policies (tactical means). Thus, for example, when the price of foreign oil is low and the assurance of a continued stable foreign supply exists, a Western home government may pursue a policy designed to maximize the positive impact of oil on its balance of trade payments by increasing the purchase of foreign oil in the belief that the infusion of capital into the oil exporting less-developed nations will expand the market for Western manufactured goods. Such a policy makes little sense, however, when the price of foreign oil is high and the assurance of continued foreign supply low. Similarly, oil companies may attempt to maximize their profits in a variety of manners. For example, they may attempt to sell increased volumes at a relatively low margin of profit per barrel or, alternatively, they may increase the profit per barrel and be content with the sale of relatively smaller volumes. Thus, the particular policies enacted by organizations attempting to realize their interests are a function of the existing state of the dynamic network environment. The following subsections briefly sketch the state of the dependence relations within the international oil industry during three periods: 1940 to 1956, 1957 to 1974 and 1975 to 1981.

The Oil Industry from 1940 to 1956

During this period the United States supply and demand situation was characterized by a general glut on the market. The end of the war relieved some of the export pressures on the U.S. oil industry although it continued to export considerable amounts (Stoff 1980). Growing demand within the U.S. and the use of conservation laws to control production enabled the corporations to effectively balance supply and demand (Darmstadter and Landsberg 1976, Nash 1968, Sampson 1975). There was, however, a growing comprehension that the center of oil production was shifting from the U.S. to the Middle East.

Despite the relative abundance of supply to quench the growing U.S. demand for oil, the United States government was actively involved in measures aimed at insuring a continued supply. These involved governmental intrusion into the industry both nationally (e.g. in attempts to establish a national oil company), and internationally (e.g. in attempts to negotiate an Anglo-American Oil Agreement)(Stoff 1980). Producing country governments in the third world were willing to sign long term concessions, primarily with the major oil companies, thus providing a relative stable source of future crude oil supply (Vernon 1976, Sampson 1975, Krueger 1975, Blair 1976). Aspects of the political environment, most notably the nationalization of the Iranian oil industry by Mossadeq, prevented the companies from viewing the foreign sources of supply as completely secure. Within the industry, intratype competition prevailed over intertype competition, especially in the international market. As a result, the industry was largely dominated by the actions of the seven largest oil companies (Sampson 1975, Blair 1976). In short, the political economy of the U.S. oil industry at this time was characterized by 1) a continuing ability to provide for the oil demand within the U.S., 2) a fear of government intervention and regulation, 3) a reasonably secure source of foreign oil and 4) a lack of competition within the industry.

The U.S. oil industry was sure of its ability to provide for the future needs of the country. This consensus of industry opinion arose largely as the result of an influential report by the Independent Petroleum Association of America (IPAA 1952). Although this report did not make an estimate of the remaining resources, it did more to influence the later pattern of resource estimates than any other single publication. Its affect was felt in two major ways: it justified the optimistic vision that was to characterize the industry until 1973 and it provided the rationale for an estimation procedure that was to produce most of the high government estimates. The Independent Petroleum Association of America report's justification of an optimistic resource future was based upon three lines of evidence. First, it makes no sense to believe that the U.S. is running out of oil when such suggestions have been advanced in the past and proven erroneous. Second, U.S. oil production was at an all time high in 1952 and continuing to increase. Third, the magnitude of U.S. proven reserves was greater in 1952 than at any previous point in history. These lines of evidence were buttressed with data suggesting that the oil industry showed a consistency of performance that would allow the linear extrapolation of historical trends into the future. In particular, the report sought to establish the existence of a correlation between drilling activity and the discovery of new reserves. This correlation was accepted by the United States Geological Survey (U.S.G.S.) and formed the basis of many of their estimates (e.g. Zapp, 1962; Hendricks, 1965; Theobald, et.al., 1972). In addition to these explicit effects, the report also had a major implicit effect. The tone of the report implied an overwhelming faith in the progress of science and technology, faith that these forces would be able to overcome any obstacles that man or earth may put in the way of the flow of natural resources.

This poses an interesting problem: Why were the estimates of this period low, in relation to those of the following period, if the industry vision of the future was optimistic? Five factors can be advanced to account for this apparent anomaly. First, the government statements made during and after the war had created a fear of shortage among the public (Stoff 1980). Second, despite the availability of supply, the industry was plagued with distribution problems resulting from the Iranian expropriation (1951-1954), the need to increase supply to the Far East during the Korean War, and the closure of the Suez Canal in 1956 (Jacoby 1974). Third, the industry feared intervention and regulation by the U.S. government (Krueger 1975, Stoff 1980). Fourth, most industry estimators believed that the estimates they were making were conservative. As Weeks (1958:432) noted, most resource estimates of this period were based upon extrapolation from the proven reserves and, thus, "(i)f the geologist's estimates of proved reserves are conservative, his predictions of the amount of oil still to be discovered . . . are likewise almost certain to be very conservative." Fifth, and perhaps most importantly, it is only through hindsight and in comparison with later developments that the estimates can be called relatively "pessimistic". If one compares them with the estimates made prior to 1940 (i.e. with the estimates which served as a base of comparison at the time the estimates were produced), the estimates made between 1940 and 1956 seem extremely "optimistic".

In short, the conventional wisdom of this period can best be classified as "restrained optimism." This restraint accounts for the fact that the estimates of this period are lower than those that followed. If this interpretation is correct, then one would expect the estimates to rise with the removal of the restraints. This occurred as a number of forces came together in the years following 1956. The most important of these forces was the resolution of the Iranian expropriation. The major oil companies were able to exclude Iranian oil from the market and to force the Iranian government to return the expropriated properties. Thus, the resolution signaled the establishment of unquestioned (albeit temporary) control by the major oil companies over the Middle East concessions (Sampson 1975, Blair 1976). Although the majors were establishing their dominance over the oil exporting governments of the Middle East, they were also encountering an increase in competition resulting from the entry of independent oil companies into the Middle East (Jacoby 1974, Sampson 1975, Krueger 1975). At the same time, there was a notable shift in government policy, the U.S. government removed itself from any attempts to regulate the industry and even stopped keeping an independent set of statistics on the industry (Nash 1968, Stoff 1980, Krueger 1975). In other words, in 1956 a number of events and processes came together in a manner that led the political economy of the industry to an approximation of the "free enterprise ideal" to which the industry pays so much lip service; the government removed itself from the marketplace, the competition between companies increased, and the logistical problems posed for international distribution were resolved. As a result, the restraints that had been in place were removed and many estimates of the following period were considerably higher.

The Oil Industry from 1957 to 1973

A number of distinctive trends characterized the supply and demand situation of this period. Most notable was the large increase in the consumption of energy that characterized the entire world, but was especially prominent in the U.S. The increasing need for petroleum brought on by this trend was exacerbated by a disproportionate increase in the use of oil (Penrose 1970, Jacoby 1974, Darmstadter and Landsberg 1976). The combination of foreign tax credits and low production costs led to a geographic shift in which the Middle East became the focus of oil production (Krueger 1975, Darmstadter and Landsberg 1976). Increasing aggregate demand, declining U.S. reserve additions, environmental constraints on the use of coal, lags in the completion of nuclear plants, and infrequent leasings of exploration properties combined with the above trends to cause an increasing U.S. dependence upon imported oil (Darmstadter and Landsberg 1976).

During this period the U.S. government assumed that transnational oil companies based in the U.S. could be trusted to act in the country's best interest. No effort was made to regulate the international petroleum industry (Krueger 1975, Stoff 1980). The government even gave up all attempts to maintain an independent data base. As a result it was dependent upon information provided by the industry (Krueger 1975). This situation arose as a political expedient. The U.S. government abdicated the responsibility for foreign relations with the Arab countries to the oil companies thus allowing the U.S. government to maintain a presence in the region while formally supporting Israel (Sampson 1975). Similarly, U.S. government intervention in the U.S. petroleum industry was minimal during this period (Nash 1968).

The Organization of Petroleum Exporting Countries (OPEC) was formed in 1960 and the OPEC countries gradually gained an enhanced bargaining position. Two main factors were responsible for this change. First, a growing number of companies were competing for oil. The entry of independents into the region also led to an increased vulnerability to pressures from the exporting countries because they were largely dependent upon sources of oil located in a single country and, thus, could not juggle their supply sources in the manner that the majors had done during the period of the Iranian expropriation of the early 1950's. Second, the OPEC countries increased the ability to gather and interpret the relevant information (Vernon 1976). As a result, the oil exporting governments gained an increased level of participation in the industry (Krueger 1975, Penrose 1970, Sampson 1975, Vernon 1976). The oil industry was characterized by a major increase in the level of competition both nationally and internationally. Nationally, the increase resulted primarily from the aggressive marketing strategies of the independent companies (Allvine and Patterson 1974). Internationally, the increase in intertype competition resulted from the entry of independents into the Middle East (Jacoby 1974, Penrose 1970, Vernon 1976, Sampson 1975). Thus, throughout much of this period the major oil companies faced the dual problems of declining market share and declining profits (Vernon 1976). In short, the political economy of this period was characterized by 1) the consistent ability of the industry to fulfill the growing U.S. demand for oil, 2) a lack of government involvement in the industry, 3) a secure source of foreign oil and 4) intense competition within the industry. It should also be noted that the growth in U.S. proven crude oil reserves, which had characterized the industry from 1945 until 1956, leveled off during the period of 1956 to 1970 and declined thereafter (Blair 1976).

During this period, the industry was unrestrainedly optimistic about the future availability of oil. Initially, this appears paradoxical when juxtaposed against the concurrent change in the discovery of new petroleum reserves within the U.S. The explanation, however, is quite straightforward. The decline in U.S. discoveries was traced to a decline in domestic exploration that accompanied the shift of capital and exploratory effort by the transnationals to the Middle East. In other words, the conventional wisdom held that the large volume of existing U.S. resources were not being proved up for economic reasons; the cost of producing oil in the Middle East was substantially cheaper.

Both the industry and the government had good reasons for assuring the public of the future availability of oil. For the industry, the reasons were primarily financial; foreign tax credits and lower production costs in the Middle East had led to a decline in the profitability of the U.S. petroleum industry. Thus, the industry favored large estimates of U.S. petroleum resources because they justified the exclusion of foreign oil from the U.S. market and, thus, prevented a further decrease in the profitability of the domestic industry. Largely as a result of these assurances, the U.S. government instituted an Oil Import Quota in 1957 (Blair 1976).(1) The government's reasons are equally clear. By the middle of the 1950's the government had essentially abandoned any attempt to regulate the petroleum industry. The abdication of government policy and planning in an area of such vital national interest could only be justified by convincing the public that enough resources existed within the U.S. to satisfy any conceivable conditions. The large estimates of remaining resources produced by the U.S.G.S. during this period served this purpose. The terminology advocated by the U.S.G.S. for classifying reserves and resources also fostered a belief in the abundance of U.S. petroleum resources (Cook 1975). In general, the public of this period were unconcerned about the future availability of oil (the industry was able to meet the increasing demand while decreasing the cost in absolute dollar terms) and optimistic about the ability of technology and the human intellect to solve problems. In addition, the actual market conditions closely approximated the industry ideal of laissez faire capitalism and the international sources

---

(1) The transnationals, whose oil was being excluded by such legislation, had only minor objections because the growth in European and Third World markets provided an outlet for their foreign crude.

of oil had remained stable despite the almost constant political turmoil within the Middle East.

Against this background of optimism, one major event successfully reoriented the entire world's attitude toward the future availability of petroleum. That event, of course, was the Arab Oil Embargo of 1973. Due to the increasing reliance upon imported oil, the U.S. companies did not possess the cushion of supply that had existed during earlier supply disruptions (Darmstadter and Landsberg 1976, Jacoby 1974). Although this was partially the result of a systematically induced supply shortage designed by the majors to squeeze out the independent producers and marketers in the United States (Allvine and Patterson 1974), the major factor involved was the shift of control over production and pricing decisions from the major oil companies to the governments of the oil exporting nations (Vernon 1976, Sampson 1975, Jacoby 1974). Interestingly, the public did not blame the Arab governments for the supply shortages of heating oil and gasoline that the consumers were forced to endure. Only seven percent of the American population blamed the Arab states for the energy crisis, against 34 percent who blamed the oil industry and 46 percent who blamed the U.S. government (Gallup Opinion Index 1974). The inability of both the government and the industry to maintain their optimistic estimates in the face of massive supply shortages and tremendous public outrage is not particularly surprising. It is important to note, however, that the major justification advanced by the OPEC countries for the curtailment of supply and the rise in prices was conservation; they claimed that the world was rapidly running out of petroleum. Thus, the OPEC nations claimed they actually were doing the world a favor by forcing the importing nations to come to grips with their dependence upon an oil based economy.

The Oil Industry from 1974 to 1981

Following the oil embargo, a markedly different situation characterized the supply and demand situation. When political trouble in the Middle East had previously created temporary problems, the major oil companies had been able to juggle their supplies and prevent any associated rise in prices. In 1973 they were unable to accomplish this and the price of oil rose dramatically (Blair 1976). Initially, the demand for petroleum remained price inelastic, but as the price continued to rise the industrialized consuming nations adjusted and demand leveled off and eventually fell. More important than changes in demand trends, however, was the control that

OPEC governments now exerted over production decisions. Unlike the major oil companies that had preferred to take their profits through high volumes of sales, the OPEC governments preferred to sell smaller volumes of oil at higher prices (Sampson 1975).

A massive shift in public opinion occurred as a result of the "energy crisis" of 1973. As a result, the U.S. government began to reassert its policy role in the oil industry (Krueger 1975, Vernon 1976). The government also began to collect independent data on industry behavior. Internationally, the energy crisis showed the petroleum exporting countries how much power they had. As a result, OPEC quickly came to exert almost absolute control over all production and pricing decisions that took place in a number of countries. The effect on the oil industry of this shift in power was not as great as one would have expected. Although a number of independent producers got squeezed out of the market, the soaring profits that were realized by the major oil companies quickly led them to understand that industry control of the entire process from exploration to marketing is not necessary (Allvine and Patterson 1974, Sampson 1975, Vernon 1976). Thus, the industry shifted its alliance from the consuming public to the governments of the oil exporting countries (Sampson 1975, Jacoby 1974). In short, the political economy of this period was marked by 1) an inability of the oil industry to guarantee supplies of crude oil to the consuming nations, 2) the reassertion of the policy and regulatory functions of the government, 3) the control of production and pricing decisions by the exporting governments, and 4) a decline in intertype competition and an increase in profitability within the industry.

These factors, combined with the fact that U.S. proven reserves had been falling since 1970, brought about a swift and profound change in industry opinion toward the future availability of oil. This shift took place in two phases. First, the industry experienced an initial pessimism resulting from the loss of control over production and pricing decisions. Second, as the companies began to realize massively increased profits and the opinion polls showed that the public blamed the oil companies for the shortages, the industry adopted OPEC's rhetoric of conservation. The rhetoric of conservation, however, is of little good if the estimates show that large quantities of crude oil remain within the United States. Thus, the political economic forces produced a situation in which lower estimates would be of practical value to the companies. Pessimism also predominated in the government after 1974. The wrath incurred as a result of the energy crisis necessitated the re-entry of the government into policy formulation and regulation of the U.S. oil industry. This was especially important since it was clear that U.S. based companies could not be trusted to conduct U.S. foreign policy in the Middle East. The production of lower estimates justified this move by the government back into the formulation of national resource policy. Thus, forces affecting both the oil industry and the U.S. government after 1973 led to lower resource estimates.

Implications

Periods characterized by specific types of resource estimates have been associated with concomitant changes in the U.S. reserve figures. The period from 1945 until 1956 was characterized by increasing domestic petroleum reserves. This, along with other factors, led to the optimistic views that were to characterize the industry until 1974. Up until 1956, however, the optimism was restrained by political economic factors; distribution of the available supply was uncertain and the economic environment did not correspond to the industry ideal of free enterprise. In 1956 two major changes took place; the growth of domestic reserves leveled off and the political economic constraints on the industry dissolved. As a result, both the industry and the government, although for different reasons, entered environments in which larger resource estimates could serve to justify their actions. The estimates of remaining U.S. oil resources increased notably over those of the preceding period. By 1970 the trend in domestic reserves had taken a downturn and the Oil Import Quota had been removed. The increasing dependence of the U.S. on imported oil was brought home to everyone by the energy crisis of 1973. This event caused a massive change in opinion among all groups; the industry, the government and the public. Pessimistic views, although carrying different meaning among the different groups, created an atmosphere in which lower resource estimates acted to the benefit of everyone involved. Thus, in all three periods it can be seen that the prevailing political economy gave rise to a conventional wisdom within those companies employing the estimators and, hence, generated resource estimates that supported the policy actions of the organization involved in the production of the estimate. The primary factors determining the conventional wisdom appear to have been 1) the state of proven domestic reserves, 2) the short term supply situation and 3) the extent to which the political economy of the industry matched the industry ideal of free enterprise. When proven reserves are remaining stable or growing, short term supply is assured and the industrial economy approximated free enterprise, then large resource estimates were produced. Deviation from these conditions, particularly if related to the short-term supply situation, restrained the size of the estimates.

Thus, the changes in the overall pattern of resource estimates displayed in Chapter 3 can be seen as a reflection of the changes in network relations in a dynamic political economic environment. Changes in those relations, particularly those affecting the short-term satisfaction of consumer demand, affect the conventional wisdom about the future availability of petroleum. Thus, such changes can lead to controversy as the newly constituted conventional wisdom clashes with the remnants of the one it replaced. As such, the preceding analysis explicates not only why the overall pattern of resource estimates took the shape that it did, but also explains why major methodological disputes arose at the times that they did (Chapter 3). These methodological disputes correspond precisely with shifts in the dynamic network relations and reflect the nomic ruptures that emerged at those times.

CHAPTER 6

NETWORK RELATIONS AND THE RELATIVE MAGNITUDE OF ESTIMATES

In chapter 4 organization of employment was shown to have a large impact upon the magnitude of the estimate. In Chapter 5 it was argued that the timing of changes between periods reflected changes in the network relations within the international oil industry. When one examines the relative magnitude of the estimates produced by the U.S. government and the U.S. based industry, however, one finds that government estimates have generally been larger than those of the industry; they were significantly larger in both the first and second periods and of approximately equal magnitude during the third period.

Two different explanations for this finding can be suggested. The first explanation treats the relative magnitude of government and industry estimates as a function of some characteristic inherent in the structure of the organizational type. This explanation suggests that, for some reason, governmental bureaucracies provide a context in which the world is viewed more optimistically than in the industrial sector. If this is true, then the relative magnitude of government and industry estimates should not be contingent; government estimates should always be larger. The second explanation treats the relative magnitude of the estimates as contingent upon the state of the network relations. According to this explanation, the fact that U.S. government estimates have been higher merely reflects the particulars of a given historical situation rather than an underlying trait of organizational structure.

This section examines two lines of evidence that undermine the former explanation and lend support to the latter. The first line of evidence compares statements made by the government and the industry during the late 1930's and 40's. The second compares the relative magnitude of government and industry estimates in Canada with those in the U.S.

EARLY U.S. ESTIMATES

From an examination of the statistical evidence (e.g. Figure 3.3) one would conclude that the government was more optimistic than the industry during the 1940-56 period. A close examination of the evidence, however, shows that this interpretation is based upon a single government estimate that was not produced until the end of the period, 1956. Thus, the apparent optimism of the government position may actually reflect an anomolous situation. Perhaps that single estimate actually represents a precursor of the government optimism that was to dominate the second period.

Evidence from two sources support this contention. First, throughout the late 1930's and the 1940's government officials made a variety of extremely pessimistic statements about the future of the U.S. oil industry. In 1939 the Interior Department issued a statement claiming that U.S. oil supplies would last only 13 years. In 1947 the Chief of the Petroleum Division of the State Department stated that sufficient oil could not be found in the United States, a sentiment echoed by the Secretary of the Interior in 1949 when he claimed that the end of U.S. oil was almost in sight (Independent Petroleum Association of America, 1952:7). This pessimism is not reflected in the estimates, however, since the government was not producing any at that time. The industry, on the other hand, viewed their estimates as evidence contradicting the government's pessimism. When made public in the 1940's these estimates were widely and rapidly accepted as valid within industry circles (DeGolyer, 1951; Pratt, 1951). In short, the government was actually more conservative than the industry for most of the 1940-56 period.

A second line of evidence supports the contention that the 1956 government estimate can best be viewed as a precursor of later estimates. As noted in Chapter 5, in

1952 the Independent Petroleum Association of America, an association of relatively small domestic producers, published a report that was highly critical of the statements that the government had been making. The 1956 government estimate and later estimates by the Geological Survey were based upon methods designed to avoid the criticisms leveled by that report. Thus, the 1956 government estimate can be viewed as a response by the government to industry criticism of their earlier pessimism.

In sum, when one examines evidence that goes beyond the actual numerical values of estimates being produced, it becomes clear that the U.S. government was more pessimistic than the oil industry for most of the 1940-56 period. A similar situation, involving actual numerical predictions is documented by Dennis (1982); in 1921 the government estimated the ultimate production of the U.S. to be considerably lower than an industry estimate that appeared four years later. Thus, the relative magnitude of estimates is not solely a function of organizational type. It is, rather, a function of organizational type existing in a situational context. This conclusion is further substantiated from an examination of Canadian estimates.

THE CANADIAN CASE

Figure 6.1 displays the historical pattern of industry and government estimates of ultimately recoverable crude oil in Canada. This pattern is notable for both its similarities with and differences from the U.S. case. Like the U.S. pattern, both industry and government estimates fell during the mid-1970's. Unlike the U.S. pattern, however, recent estimates by the Canadian government have been consistently lower than those of the industry. This section examines these features in light of the relative position of the U.S. and Canadian governments in the international oil industry.

The similarity between the Canadian and American aggregate trends can be traced to changes in the political economy of the international oil industry that affected both countries similarly; the loss of secure availability from foreign sources and the associated realization that future supply was not assured. Indeed, the effect upon Canada was more profound than in the U.S. The United States was a net importer of petroleum long before the shocks induced by the Arab Oil Embargo of 1973. Shortly following that shock, however, Canada shifted from a net

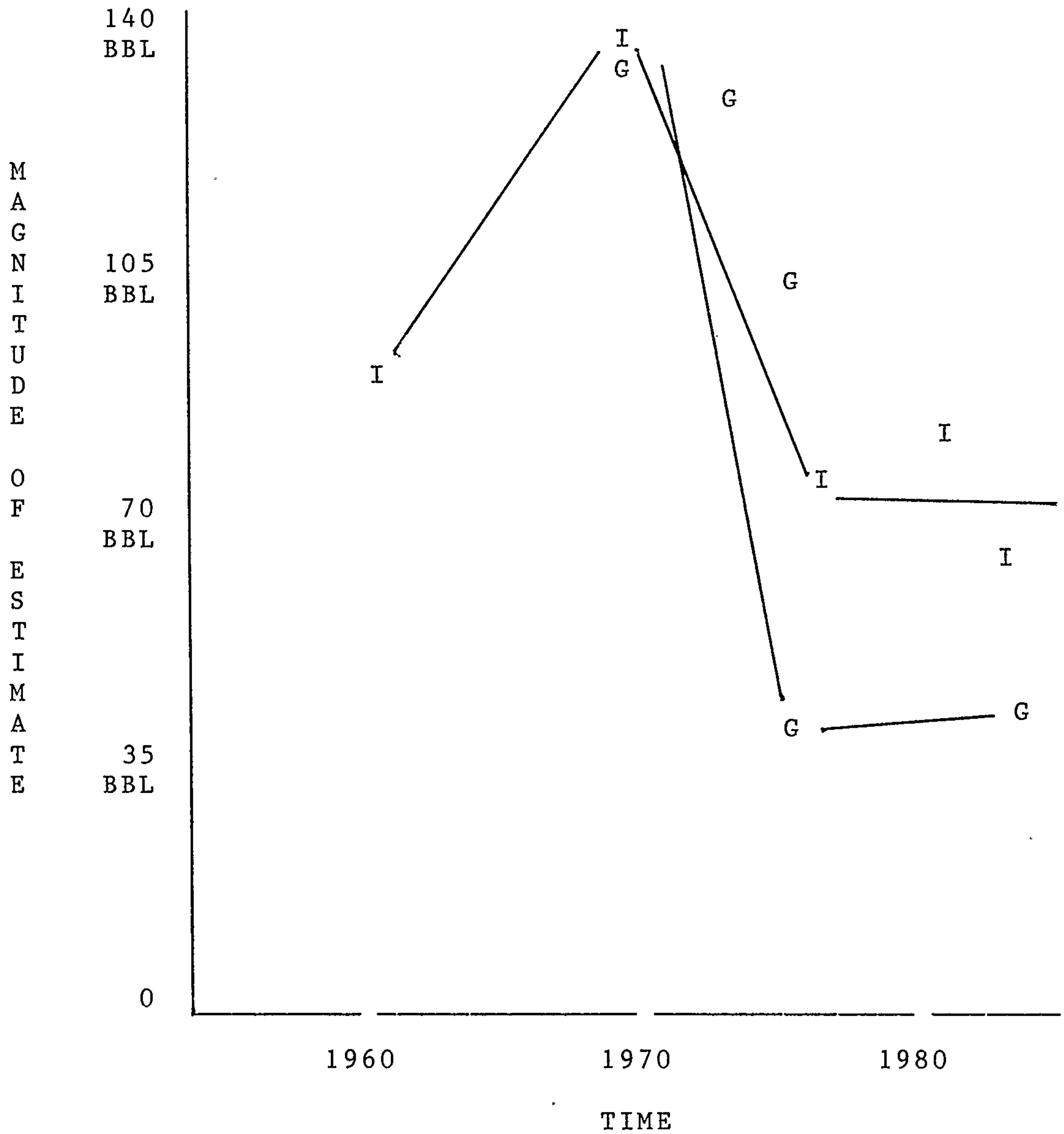


FIGURE 6.1: SCATTERPLOT AND TRENDS IN ESTIMATES OF CANADIAN CRUDE OIL RESOURCES (BBL = BILLION BARRELS).

G = Government Estimates
I = Industry Estimates

exporter of oil to a net importer (see Table 6.1). Thus, in both cases resource estimates fell as a function of the industries inability to deliver short-term supply.

YEAR	EXPORTS	IMPORTS	BALANCE	OIL	GAS
1969	202.7 Mbl	193.4 Mbl	+ 9.4 Mbl	141 Bbl	725 Tcf
1970	244.4	207.9	36.5		
1971	270.5	245.1	25.4		
1972	340.9	281.6	59.3	134	907
1973	420.2	328.2	92.0	99	784
1974	333.4	291.7	41.7		
1975	262.7	298.6	-35.9		
1976	182.7	277.2	-94.5	38	282

TABLE 6.1: A COMPARISON OF THE IMPORT/EXPORT BALANCE OF CANADIAN CRUDE OIL WITH ESTIMATES OF ULTIMATELY RECOVERABLE OIL AND GAS RESOURCES MADE BY THE GEOLOGICAL SURVEY OF CANADA (FROM SHAFFER, 1983:223,224).

In order to understand the implications of the trends shown in Table 6.1, one must realize certain peculiarities of the Canadian energy market. In the early 1950's Canada began to export crude oil to the United States. This was accomplished through two pipelines: the Interprovincial Pipeline (connecting Edmonton and Sarnia by way of Superior, Wisconsin) and the Trans Mountain Pipeline (connecting Edmonton with Vancouver and the Pudget Sound area of Washington State). These exports, initially centered on the west coast of the U.S. (since the U.S. was using California oil as supply for the Korean conflict), reached a peak in 1957. They accounted for over 30 percent of total production (Canadian Petroleum Association, 1972:75,101). The curtailment of this export market with the resolution of the Korean conflict and the reopening of the Suez Canal led Canadian independents to lobby for increased access to the markets of eastern Canada.

A direct conflict between the Canadian independents and the transnational oil companies resulted. The independents wanted access to eastern Canadian markets while the transnationals wanted to continue supplying the region with oil from Venezuela that was both cheaper and more profitable than western Canadian crude (Foster, 1979). The Borden Commission resolved this dispute by erecting an artificial barrier, the Ottawa Valley Line, that segmented the Canadian market into two parts. Those areas west of the line would be supplied by Canadian oil while those east of the line would be reserved for imports. To appease the independents, the government supported increased exports to the United States (and indeed got the U.S. to exempt Canada from limitation under its Oil Import Quota policy). Thus, beginning in the early 1960's exports as a percentage of production grew rapidly; reaching fully two-thirds of production by 1973 (Shaffer, 1983:161). Thus, in both the construction of the various pipelines and the policies implemented under the "National Oil Policy", the actual flow of materials was north-south rather than east-west. In other words, the policies being followed were in effect predicated upon a continental energy market rather than upon a national energy market.

The justification for pursuing such a policy was essentially economic; Canadian oil could be found, developed and produced for roughly 80 cents a barrel less than U.S. oil (Oilweek, 1972:79) and the cost of domestic oil in Toronto was roughly 90 cents per barrel higher than the cost of imported oil (Combines Investigation, 1981(2):34). As a result, the logic of such a policy dissolved with the quadrupling of imported oil prices that accompanied the embargo of 1973-4. Although the Canadian government responded by constructing an Edmonton to Montreal pipeline, the capacity of that line (250,000 barrels/day) accounted for only one third of the demand for oil in the east at the time of its completion. As a result, Canada, despite the now unified market, was unable to curtail imports. This raised two important problems: 1) reconciling the difference between the import price and the "made-in-Canada" price and 2) the disposition of economic rents that were accruing to the transnational oil companies as a result of the massively increased prices (Foster, 1979; Shaffer, 1983). Unlike the United States, Canada opted to resolve the former problem through federal control of pricing. Price was tied neither to the cost of imports nor to the proportion of imports consumed. Thus, the shift from net exporter to net importer status had profound financial implications for the Canadian government since it forced the government to subsidize imports.

The disposition of economic rents posed an interesting double bind for the transnational oil companies; if they repatriated their profits to the parent company in the United States they would create severe strains upon the balance of payments but if they increased their investment in the Canadian economy they would be accused of subjecting more and more sectors to foreign control. It was in this setting that those individuals Shaffer (1983) has called the "national bourgeoisie" came to view control of oil as a means of changing international power relationships in their favor.(1) This view has been reflected in the energy policies of the Canadian federal government since the mid-1970's. Canadian ownership has been directly increased through the creation of a national oil company (PetroCanada) and indirectly subsidized through differential government grants dependent upon the percentage of Canadian ownership (e.g. the Petroleum Incentives Program).

Thus, a structural basis for the differential relationship between relative magnitude of estimates produced by the United States and Canadian governments and the international oil companies within those respective countries can be seen. In the United States, the oil companies are closely connected with the rise of U.S. economic domination over the "Free World" and, hence, government estimates have served to justify policies aimed at improving the position of the U.S. based transnationals throughout the world. Alternatively, the Canadian government, at least since the mid-1970's, has viewed the transnational oil companies as foreign intruders whose interests are not to be treated as coextensive with those of the Canadian people.

---

(1) A similar attitude has arisen in Mexico. See, for example, Saxe-Fernandez (1980).

This difference is also reflected in the impact resource estimates have been accorded in the policy process. In the U.S., the government produced resource estimates were neither mandated for explicit use in arriving at particular policy choices nor were they decisive criteria for any policy choices. Indeed, in many cases the government did not even utilize its own estimates when making long-term supply and demand analyses.(1) In addition, there exists some evidence that policy criteria heavily influence the estimates that are eventually produced.(2)

The ad hoc utilization of resource estimates that has characterized most energy planning in the United States differs markedly from the utilization such estimates receive in Canada. Although the Institute of Sedimentary Petroleum Geology is buried in an isolated corner of the bureaucratic structure of the Geological Survey of Canada, the resource estimates they produce are forwarded directly to the Director of Petroleum Resources in the Department of

---

(1) For examples, see McKelvey's testimony in Joint Economic Committee (1975).

(2) Wildavsky and Tanenbaum (1981:238-247) argue that this happened with the Market Oriented Program Planning Study (MOPPS) undertaken by officials of the Energy Resources and Development Administration in 1977. For an alternative account, however, see Cochrane (1981:590-591).

Energy, Mines and Resources. There the estimates are subjected to economic analysis (e.g. costing out the development of fields in various locations and of various sizes) and the resulting scenarios are explicitly utilized in formulating energy policy at the highest levels of government on an ongoing basis. In addition, the National Energy Board makes both explicit and decisive use of their own estimates when making a decision upon whether or not to allow increased exports.

To summarize, both the structural difference in the pattern of estimates produced by U.S. and Canadian government estimators and the differences in impact those estimates have had in the formulation and implementation of policy decisions can be traced to differences in the political economy of the two nations. In the U.S., where the government is merely attempting to regulate the excesses of an industry traditionally perceived by serving U.S. economic interests, the government has produced estimates which justify a "hands off" attitude and has often utilized industry data rather than their own estimates in formulating policy. In Canada, where the government is actively attempting to regain control of its resources from the domination of foreign transnationals (and prevent further slippages of economic power to those provinces that own the mineral rights), the government has both produced and utilized estimates that are more conservative than those produced by the industry.

IMPLICATIONS

The findings from the preceding sections provide a strong basis for extending the theoretical interpretation of the organization effect documented in Chapter 4. Place of employment should not be viewed as an isolated variable impacting upon the production of scientific knowledge. Instead, place of employment should be viewed as a mediating variable between national policies and sociocultural systems on the one hand and the "scientific tradition" and an individual researcher's contribution to it on the other. It is interesting to note that recent studies in the anthropology of science, although based upon markedly different research methodologies, have reached identical conclusions (e.g. Anderson, 1981).

CHAPTER 7

SUMMARY AND CONCLUSIONS

SUMMARY

Estimates of ultimately recoverable, conventional U.S. crude oil resources, when compared, yield a distinct historical pattern definable on the basis of three criteria: 1) the mean magnitude of the estimates produced within a chronological period; 2) the amount of variation around that mean; and 3) the timing of the breaks between chronological periods. From 1940 to 1956 the estimates were relatively low and consensual. From 1957 to 1974 the estimates were relatively high and showed greatly increased variability. From 1975 to 1981 the estimates were of intermediate magnitude and highly consensual. The accounts used to explain the differences between particular estimates are inadequate to explain this pattern (Chapter 3).

Changes in the mean magnitude of the estimates through time reflect the movement between categories within the total estimate; chronological change in the magnitude of past production and proven reserves accounts for chronological change in the estimates of unknown resources. In other words, estimators base their perceptions of future outcomes upon current experience and utilize past production and proven reserves figures to constitute that experience. These figures, however, are not uniformly interpreted. Thus, there exists a certain amount of variation around the mean magnitude at any given point in time. Factors both internal and external to the practice of science are ultimately responsible for generating that variation. External factors, however, are responsible for the variation in the interpretation of proven reserve figures. Differences in interpretation do not follow from the adoption of different estimation methodologies but, rather, appear as a function of employment in a particular type of organization. Thus, the most significant variable explaining both the variation around the mean at a given time and changes in the extent of that variability through time is organizational context and its interaction with proven reserves. This suggests the existence of organizational cultures that impact upon the selection of core assumptions through differential interpretation of the proven reserves figures. This process accounts for 1) differences in the magnitude of the estimates produced within an organizational type through time and for 2) differences between the magnitude of estimates produced by different organizational types at a given point in time. It leaves unanswered, however, the process that generates the zeitgeist of a particular organizational culture (Chapter 4).

Changes in the dependence relations among organizational actors within the political economy of the international oil industry influence the manner in which organizations pursue their interests. Structural changes in this political economic network are clearly related to the timing of the breaks between periods. The 1956-7 break relates to a series of events that established the economic domination of U.S.-based transnational corporations over the international industry. Similarly, the 1974-5 break followed shortly after that domination was transferred to the oil exporting countries. These structural changes are also related to the changes in the mean magnitude of the estimates; large estimates were produced by U.S. estimators when U.S. based corporations effectively dominated the industry and, hence, could assure the satisfaction of U.S. consumer demand. Smaller estimates were produced when these conditions did not obtain. Thus, changes in the means used to pursue organizational interests are related to changes in the magnitude of the estimates produced within an organizational type through time. The relationship between organizational interests and the differences among estimates produced by different types of organizations at the same time is less clear (Chapter 5). One possible explanation for this finding will be examined later in this chapter.

The effect of place of employment upon the magnitude of the estimate can be interpreted in two distinct manners. The first traces the effect to a characteristic of the organization while the second treats the effect as contingent upon the existing state of a dynamic network of organizational relations. Two lines of evidence, early U.S. estimates and the Canadian case, discount the explanatory utility of the former account and harmonize with the latter (Chapter 6).

CONCLUSIONS

These substantive findings shed light upon a number of topics. First, what is the nature of the relationship between organizational context and the production of scientific knowledge? Second, what dimension underlies the cluster of characteristics in the political economy of the international oil industry that correlate with changes in estimate magnitude? Third, what are the implications for the attributional and interest theories in the science studies literature?

Organizational Context and Scientific Knowledge

Until recently the content of science was viewed as immune from social influence. According to Shils (1979:459),

> The influence of government through its financial powers on the scale and direction of scientific research has been much observed and discussed in recent decades. No attention has been given to the influence of government on the intellectual content of the natural sciences because that is something which is beyond the power of government to affect. External influences might affect the choice of subject-matter but they cannot influence the intellectual content of what is said about those subject-matters, except in infrequent cases like that of the intrusion of political beliefs into genetics in the Soviet Union. The natural sciences have very strong traditions and those who carry them on through their work are sufficiently dominated by them to be resistent to efforts to exercise political influence over what scientists say about their subject-matters.

Thus, the view that organizational context affects the production of scientific knowledge has traditionally been dismissed as misguided. By contrast, the present findings firmly support this view; place of employment has been shown to have a major impact upon the production of a specific type of scientific knowledge, the numerical value of a theoretical prediction.

But another question remains. Might not the differences in estimate magnitude be traceable to differences in "values" rather than to differences in "facts"? Analysts familiar with the use of scientific knowledge in politicized policy debates frequently trace the origin of the debates to differences in the world views of the protagonists that impact upon how they interpret the facts. If this is the case, then the differences among estimates do not necessarily reflect scientific differences. Mazur (1981), in his analysis of the controversy over acceptable levels of exposure to radiation, provides a nice illustration of this position. According to Mazur, the technical controversy centered not upon the statistical "facts" of how many cancers can be expected from a given level of radiation, but rather upon how these facts should be interpreted. One side, those favoring a lower level of acceptable exposure to radiation, held that any increase in exposure leads to an increased incidence of cancer. The other side, those favoring a higher level of acceptable exposure to radiation, held to a nonlinear interpretation of the relationship; a threshold level exists and any exposure below that level is safe.

Although superficially plausible, the distinction between "facts" and "values" as utilized by Mazur is inapplicable in the present case. Resource estimates, as numerical predictions, represent the "facts" that underpin a variety of government and industry policy deliberations.

Any one of several policy positions can be supported by a given numerical value, however, depending upon how that number is interpreted. In other words, numbers, like everything else, are indexical. Resource estimates have been interpreted through reference to perspectives on resource scarcity that vary from the position that scarcity is an economic condition to the position that scarcity reflects a physical shortage of materials.(1) Thus, while Mazur's distinction may provide a useful basis for connecting the numerical values of resource estimates to the associated policy debates, it does not provide a useful basis for explicating the differences in the numerical predictions themselves.

Stated another way, Mazur makes a useful distinction, but that distinction is not between "facts" and "values". The present analysis has shown that, at least in this case, "values" impact upon the production of what Mazur terms "facts". A more accurate representation of Mazur's distinction is captured by the terms "data" and "interpretation". Such a distinction, however, is not necessarily coextensive with a distinction between facts an values. More significantly, the existence of a distinction

---

(1) For a concise treatment of the differences in these perspectives and their relationship to policy debates, see Congressional Research Service (1978).

between facts and values is not supported by the above research.

The Control of Oil and Information

Chapters 5 and 6 outlined a number of characteristics within the political economic context of the international oil industry that correlate with changes in the mean magnitude of the estimates through time: the extent of government involvement in the oil industry, the assurance that short-term demand can be satisfied without inconveniencing the consumer, changes in the proven reserves figures, etc. If these characteristics are responsible for an organizationally based zeitgeist, to what extent can this cluster of variables be treated as the manifestation of a single underlying dimension?

One such concept, the control of oil, has characterized the international industry since its inception. The ability of a small number of corporations and/or governments to effectively control the international industry has been facilitated by both geology and institutional arrangements. Geologically, the vast majority of the worlds petroleum exists in a small number of very large pools in a few locales. Institutionally, transnational corporations entered into long term concessions with sovereign nations possessing sovereign control over subsoil mineral rights. Through a series of systems involving jointly owned operating companies and restrictive long term contracts between vertically integrated corporations, the transnationals were able to limit output to predetermined growth rates and eliminate differences in delivered prices throughout the world and, hence, maintain control over both supply and demand (Blair, 1976).

The breaks between periods reflect changes in the control of oil. Up until the early 1970's control rested with the transnational companies. It was not until the mid-1950's, however, that this control rested with U.S. based corporations. Beginning with the Second World War and accelerating after its conclusion, control over Middle East concessions was transferred from British to American corporations. The pinnacle of this process occurred with the restructuring of access to Iranian resources that followed the expropriation of British Petroleum's holdings. Similarly, the 1974-5 break correlates with the dawning realization that control over production, pricing, and marketing of foreign oil no longer resided with the transnationals.

But how did the transnational corporations prevent sovereign nations from asserting control over their resources for as long as they did? A number of factors are involved. Initially, the strength of the companies flowed from their financial position; they could mobilize large sums of capital that were unavailable to the host governments. In addition, the companies controlled both the technology and the manpower necessary for exploration and production. The most effective mechanism for maintaining control during the glut of the 1950's and 60's, however, was the ability of the companies to deny markets to host governments with which they had a dispute. Following the Korean War a glut of oil on the market placed bargaining power in the hands of the ultimate purchaser. These factors provide, at best, a partial explanation; each had drawbacks and, in any event, the companies rarely used them as weapons against the host governments.

A more significant factor was the control of information. Host governments simply did not understand the complexities of an industry that juggled crude oil from a variety of sources and manipulated transfer prices between various subsidiary corporations. The formation of OPEC in 1960, however, institutionalized cooperation between host governments that had previously had little contact and, hence, provided a forum for the exchange of information. Thus, it was the increased understanding of the entirety of the industry coupled with a change in the market situation (which placed more power in the hands of suppliers) and the arrival of a catalyst, Quadaffi, unawed by the reputation of the oil companies that set the stage for the transfer of control from the companies to the host governments in the early 1970's.

If the control of oil has historically been related to the control of information, then one must also consider the possibility that government estimates are merely a reflection of information selectively released by the industry. At first blush, this contention makes little sense; government and industry estimates varied greatly between 1957 and 1974. Two lines of evidence, however, lend credence to the suggestion. First, despite their numerical differences, government and industry estimates were seen as implying similar policies during the 1957 to 1974 period. Second, massive revisions of the government estimates occurred in 1956 and 1975; revisions that were made in direct response to severe industry criticism of the previous government estimates.(1) The findings of the present analysis, however, shed little light upon the extent of government dependence upon industry information.

---

(1) For an expanded treatment of these themes, see Bowden (forthcoming).

Attribute versus Interest

Theoretically, this thesis aimed to test the relative explanatory utility of two fundamentally different types of explanation within the science studies literature; attribution theory and interest theory. The results, rather than confirming the relative utility of one account over the other, suggest the need to synthesize the insights of both accounts into a wider explanatory framework. Both internal and external factors are relevant to an understanding of the variation among crude oil estimates and, hence, neither the attribution nor the interest explanation appears to be sufficient in an of itself.

This conclusion, however, must be tempered with an understanding of the extremely crude nature of the empirical indicators that were utilized. Estimation methodology, for example, represents only one aspect of scientific practice. Indeed, core assumptions, the aspect of scientific practice given most weight in the substantive analysis, could not be measured directly because of the relatively small number of cases for which they can be established from published information. Similarly, the existence of a substantial organization effect does not confirm the interest explanation; factors other than organizational interests may be responsible for that effect.

Despite the large proportion of the variance explained, this research must be viewed as fundamentally exploratory. Due to the crude nature of the empirical indicators, there can be little doubt that the statistical models are mis-specified. Further research aimed at identifying the precise relationship among a wider range of internal and external features must be undertaken before any strong conclusions can be reached about the precise nature of the interface between the attribution and interest theories.

It is possible, however, to sketch the broad outline of a linkage between the two theoretical types. The linkage follows from the differing conception of knowledge embedded in the two theories. Attribution theorists tend to treat knowledge as a localized product while interest theorists view it as the result of consensus among a network of individuals in disparate settings. Thus, it is possible that knowledge becomes constituted on a localized basis through a process of attribution and that the emergence of similar attributions throughout a network of local settings reflects the operation of interests. The validity of this hypothesis, however, rests upon future research.

Future Research

Each of the preceding three subsections suggested the need for further research. The most significant of these suggestions involves an extension of the analysis to incorporate the connection between resource estimates as numerical values and their use in support of particular policy options through a process in which the numerical value is invested with meaning through reference to a perspective on resource scarcity. This research would provide a basis for examining the relationship between data and its interpretation in the resource assessment arena.

Of more central theoretical importance, such research would allow a closer examination of the utility of the interest model of explanation. As was noted earlier, the relationship between organizational interests and the relative magnitude of the estimates produced by different organizations at the same time was not always clear. This occurs because the resource estimates, as numerical values, have indexical meanings in the policy context depending upon how they are interpreted. If, as hypothesized by interest theory, scientific knowledge provides a resource for the pursuit of interests, then interests should impact upon the constellation of data and interpretation that are directly tied to the advocacy of policy options. In other words, to treat the numerical value of the estimate as the product of interests may be an oversimplification.

If this is true, then organizations which produce widely divergent estimates and advocate similar policies should draw upon differing perspectives on resource scarcity in order to reconcile the differences between their estimates in the policy forum. In other words, perspectives on resource scarcity should act to contrast the significance invested in numerical differences among estimates produced by organizations advocating similar policies and to expand the significance invested in the numerical differences among estimates produced by organizations advocating different policies. If this hypothesis is borne out, it stands as strong confirmation of the utility of the interest model. The answer, however, awaits future research.

BIBLIOGRAPHY

Albers, J.P., M.D. Carter, A.L.Clark, A.B. Coury and S.P. Schweinfurth
1973 Summary Petroleum and Selected Mineral Statistics for 120 Countries, Including Offshore Areas. Geological Survey Professional Paper 817. Washington, D.C.:U.S. Government Printing Office

Aldrich, H.E.
1979 Organizations and Environments. Englewood Cliffs, N.J.:Prentice-Hall.

Aldrich, H.E. and J. Pfeffer
1976 "Environments of organizations," Annual Review of Sociology 2:79-105.

Allen, T.
1966 "Performance of communication channels in the transfer of technology," Industrial Management Review 8:87-98.

Allen, T. and S. Cohen
1969 "Information flow in research and development laboratories," Administrative Science Quarterly 14(1):12-20.

Allvine, F. and J. Patterson
1974 Highway Robbery: An Analysis of the Gasoline Crisis. Bloomington:Indiana University Press.

American Petroleum Institute
1979 Reserves of Crude Oil, Natural Gas Liquids, and Natural Gas in the United States and Canada as of December 31, 1978. Volume 33, June 1979.

1983 Basic Petroleum Data Book 3(1) Dallas:American Petroleum Institute.

Anderson, R.
1967 Community for Research: An Anthropologist in the Enrico Fermi Institute for Nuclear Studies. Unpublished MA thesis, Department of Sociology, University of Chicago.

1975 Building Scientific Institutions in India: Saha and Bhabha. Montreal:McGill University Centre for Developing Area Studies.

1981 "The necessity for field methods in the study of scientific research," Pp. 213-244 in E. Mendelsohn and Y. Elkana (eds), Sciences and Cultures. Sociology of the Sciences, Volume V. Dordecht:D. Reidel.

Arps, J.J., M. Mortanda and A.E. Smith
1971 "Relationship between proved reserves and exploratory effort," Journal of Petroleum Technology 23(6):671-675.

Ascher, W.
1978 Forecasting: An Appraisal for Policy-Makers and Planners. Baltimore:Johns Hopkins.

Averitt, P.
1961 Coal Reserves of the United States. United States Geological Survey Bulletin 1136. Washington D.C.:U.S. Government Printing Office.

Ayres, E.
1955 "Energy resources for the future," Oil and Gas Compact Bulletin, 14(1):20.

Baker, R. and J. Nelder.
1978 The GLIM System: Generalized Linear Interactive Modelling. Oxford:Numerical Algorithms Group.

Barnes, B.
1974 Scientific Knowledge and Sociological Theory. London:Routledge and Kegan Paul.

1977 Interests and the Growth of Knowledge. London:Routledge and Kegan Paul.

1981 "On the 'hows' and 'whys' of culture change," Social Studies of Science 11(4):481-498.

1982 T.S. Kuhn and Social Science. London: Macmillan.

Ben-David, J. and T. Sullivan
1975 "Sociology of science," Annual Review of Sociology 1:203-22.

Berg, R.R., J.C. Calhoun and R.L. Whiting
1974 "Prognosis for expanded U.S. production of crude oil," Science 184(4):331-336.

Blair, J.
1976 The Control of Oil. New York:Vintage.

Blalock, H.
1969 An Introduction to Social Research. Englewood Cliffs, NJ:Prentice Hall.

Bloor, D.
1976 Knowledge and Social Imagery. London:Routledge and Kegan Paul.

Bonillias, Y.
1974 "World crude oil reserves," Unpublished paper presented to the Western Gas Processors' and Refiners Association, October 1974.

Bowden, G.
"The social construction of validity in estimates of U.S. crude oil resources," Social Studies of Science (forthcoming).

Brannigan, A.
1980 "Naturalistic and sociological models of the problem of scientific discovery," British Journal of Sociology 21:559-73.

1981 The Social Basis of Scientific Discoveries. Cambridge:Cambridge University Press.

Canadian Petroleum Association
1972 1971 Statistical Yearbook. Calgary:Canadian Petroleum Association.

Caplow, T.
1954 The Sociology of Work. New York:McGraw-Hill.

Cochrane, J.L.
1981 "Carter energy policy and the ninety-fifth congress," Pp. 547-600 in C.D. Goodwin (ed.) Energy Policy in Perspective: Today's Problems, Yesterday's Solutions. Washington, D.C.: Brookings Institute.

Collins, H.M.
1975 "The seven sexes: A study in the sociology of a

phenomenon, or the replication of experiments in physics," Sociology 9:205-224.

1981a "Stages in the empirical programme of relativism," Social Studies of Science 11(1):3-10.

1981b "Son of seven sexes: The social destruction of a physical phenomenon," Social Studies of Science 11(1):33-62.

1981c "The place of the 'core-set' in modern science: Social contingency with methodological propriety in science," History of Science 19(1):6-19.

1983 "The sociology of scientific knowledge," Annual Review of Sociology 9:265-85.

Collins, R. and S. Restivo
1983 "Robber barons and politicians in mathematics: a conflict model of science," Canadian Journal of Sociology 8(2):199-227.

Combines Investigation
1981 The State of Competition in the Canadian Petroleum Industry: Findings, Issues and Remedies. Ottawa:Supply and Services.

Cook, E.
1975 "Undiscovered or undeveloped crude oil 'resources' and national energy strategies," Pp. 97-106 in J. Haun (ed.), Methods of Estimating the Volume of Undiscovered Oil and Gas Resources. Tulsa:American Association of Petroleum Geologists.

Congressional Research Service
1978 Are we running out? A perspective on resource scarcity. Study prepared for the Committee on Interstate and Foreign Commerce, Subcommittee on Energy and Power. Committee Print 95-57, 95th Congress, 2nd Session.

Conrad, J.
1982 "Scientific expertise in technological controversies," Inernational Political Science Review 3(3):315-322.

Coqueron, F.G., H.D. Hammar and J.G. Winger.
1958 "Future growth of the world petroleum industry,"

New York:Chase Manhattan Bank, Petroleum Department, 1-47.

Cram, I.H. (ed.)
1971 "Future petroleum provinces of the United States --Their geology and potential. American Association of Petroleum Gologists, Memoir 15. Tulsa:American Association of Petroleum Geologists.

Crane, D.
1972 Invisible Colleges: Diffusion of Knowledge in Scientific Communities. Chicago:University of Chicago Press.

Darmstedter, J. and H. Landsberg
1976 "The economic background," Pp.15-38 in R. Vernon (ed.), The Oil Crisis. New York:Norton.

Davis, W.
1958 "A study of the future productive capacity and probable reserves of the U.S," Oil and Gas Journal 56(8):105-119.

DeGolyer, E.
1951 "Editorial comment," Journal of Petroleum Technology 3(1):9-10.

DeNovo, J.A.
1955 "Petroleum and the United States Navy before World War I," Mississippi Valley Historical Review XLI(March):641-656.

1956 "The movement for an aggressive American oil policy abroad, 1918-1920," American Historical Review 61:854-876.

Dennis, M.
1982 "Drilling for dollars: The making of petroleum reserve estimates, 1921-1925," Unpublished B.A. thesis, Department of History and Sociology of Science, University of Pennsylvania.

Desprairies, P.
1977 Worldwide Petroleum Supply Limits: Executive Summary. Paris:Institute Francais du Petrole.

1978 World Energy Resources 1985-2020, Volume 3, Oil and Gas Resource Guildford, UK: IPC Science and Technology Press.

Dolton, G.L., K.H. Carlson, R.R. Charpentier, et. al.
1981 Estimates of Undiscovered Recoverable Conventional Resources of Oil and Gas in the United States. United States Geological Survey Circular 860. Washington D.C.:U.S. Government Printing Office.

Duncan, D.C. and V.E. McKelvey
1963 "U.S. resources of fossil fuels, radio- active minerals and geothermal energy," Table 9, Appendix A, Pages 43-45 of Federal Council for Science and Technology, Research and Development on Natural Resources.

Elliot, M.A. and H.R. Linden
1968 "A new analysis of U.S. natural gas supplies," Journal of Petroleum Technology 20(2):135-141.

Energy, Mines and Resources
1973 An Energy Policy for Canada Phase 1. Volumes 1-2. Ottawa:Department of Energy, Mines and Resources.

1976 An Energy Strategy for Canada: Policies for Self-Reliance. Ottawa:Department of Energy, Mines and Resources.

1977 Oil and Natural Gas Resources of Canada, 1976. Ottawa:Department of Energy, Mines and Resources.

1980 National Energy Program, 1980. Ottawa:Supplies and Services.

1982a National Energy Program Update -- A Summary. Ottawa:Supplies and Services.

1982b "Current estimates of oil and gas resources of Canada, June 1982," News release, Petroleum Resources Appraisal Secretariat, Geological Survey of Canada, Department of Energy, Mines and Resources.

Exxon Corporation.
1975 Unpublished estimate, cited by Stannage (1979:114).

1976 U.S. Oil and Gas Potential. Exploration Department, Exxon Corporation U.S.A. (March, 1976).

1982 How Much Oil and Gas? Exploration Department, Exxon Corporation U.S.A. (April, 1982).

Ford Foundation
1974 Exploring Energy Choices. Washington D.C.

Foster, P.
1979 The Blue-Eyed Shieks: The Canadian Oil Establishment. Toronto:Collins.

1982 The Sourcerer's Apprentice: Super-Bureaucrats and the Canadian Energy Mess. Toronto:Collins.

Fowler, R.G.
1977 "The longevity and searchworthiness of petroleum resources," Energy 2:189-195.

Frank, A.W.
1979 "Reality construction in interaction," Annual Review of Sociology 5:167-191.

Gallup Opinion Index
1974 Opinion Index Number 104. February, 1974.

Gillette, R.
1974 "Oil and gas resources: Did the U.S.G.S. gush too high?" Science 185(7):127-130.

Gonzalez, R.
1957 "Petroleum for our future progress," Journal of Petroleum Technology, March:44-51.

Grenon, M. (ed.)
1975 First IIASA Conference on Energy Resources. Laxenburg, Austria:International Institute for Applied Systems Analysis

Grossling, B.
1975 In Search of a Statistical Probability Model for Petroleum Resource Assessment. United States Geological Survey Circular 724. Washington D.C.:U.S. Government Printing Office.

1976 Window on Oil. London:Financial Times.

Habermas, J.
1972 Knowledge and Human Interests. London: Heinemann.

Halbouty, M.T. and J.D. Moody.
1979 "World ultimate reserves of crude oil," Proceedings, Tenth World Petroleum Congress, Bucharest, Volume 2:291-302.

Hall, T.
1960 "It takes an optimist to find oil," Bulletin of the American Association of Petroleum Geologists 44(7):984-6.

Harrison, J.M.
1963 "The nature and significance of geological maps," Pp.37-63 in C.C. Albritton (ed.) The Fabric of Geology. San Francisco: W.H. Freeman.

Haun, J. (ed.)
1975 Methods of Estimating the Volume of Undiscovered Oil and Gas Resources. Tulsa, Oklahoma: American Association of Petroleum Geologists.

Hea, J.B.
1981 Director General of Petroleum Resources, Department of Energy Mines and Resources, Personal Interview, September 7.

Hedberg, H.
1975 "The volume-of-sediment fallacy in estimating petroleum resources," Pp. 161 in J.D. Haun (ed), Methods of Estimating the Volume of Undiscovered Oil and Gas Resources. Tulsa:American Association of Petroleum Geologists.

Heise, D.
1972 "Employing nominal variables, induced variables, and block variables in path analyses," Sociological Research and Methodology 1(2):147-70.

Hendricks, T.
1965 Resources of Oil, Gas, and Natural-Gas Liquids in the United States and the World. United States Geological Survey Circular 522. Washington D.C.:U.S. Government Printing Office.

Hendricks, T. and S. Schweinfurth
1966 "The United States resource base of petroleum," U.S. Department of Interior, unpublished memo, September 14, 1966. Quoted in United States Petroleum Through 1980, 1968: U.S. Department of Interior, 92 pp.

Hidy, R.W. and M.E. Hidy
1955 Pioneering in Big Business, 1882-1911: A History of Standard Oil Company (New Jersey) Volume 1. New York:Harper.

Hill, K., H. Hammer and J. Winger
1957 "Future growth of the world petroleum industry," Paper presented at the Spring Meeting of the American Petroleum Institute, Division of Production, Rocky Mountain District, Casper, Wyoming, April 25, 1957.

Hubbert, M.K.
1956 "Nuclear energy and the fossil fuels," Proceedings, American Petroleum Institute Section on Drilling and Production Practice, 7-25.

1962 Energy Resources. National Academy of Sciences-National Research Council, Publication 1000-D. Washington D.C.

1965 "Reply," Bulletin of the American Association of Petroleum Geologists 49(10):1720-1727.

1966 "Reply to J.M. Ryan," Journal of Petroleum Technology 18:284-286.

1967 "Degree of advancement of petroleum exploration in the United States," Bulletin of the American Association of Petroleum Geologists 51:2207-2227.

1969 "Energy Resources," Pp. 157-242 in National Academy of Science-National Research Council, Resources and Man. San Francisco:W.H. Freeman.

1971 "The energy resources of the earth," Scientific American 225(3):61-70.

1973 "Survey of world energy resources," Canadian Mining and Mettallurgical Bulletin 66(735):37-53.

1974 "U.S. energy resources: A review as of 1972," Committee on Interior and Insular Affairs, 93 Congress, 2 Session, Washington D.C.

1978 "U.S. petroleum estimates, 1956-1978," Annual Meeting Papers, Production Department, American Petroleum Institute, Dallas, Texas.

Independent Petroleum Association of America
1952 Petroleum in the Western Hemisphere. Report of the Western Hemisphere Oil Study Committee. Washington D.C.:Independent Petroleum Association of America.

Ion, D.
1963 "Discussion," Proceedings of Sixth World Petroleum Congress, Frankfurt, Germany, June 1963, 8(9):111-112.

1975 Availability of World Resources. London:Graham and Trotman Ltd.

Irving, J., I. Miles and J. Evans (eds.)
1979 Demystifying Social Statistics. London:Pluto Press.

Ise, J.
1926 The United States Oil Policy. New Haven.

Jacoby, N.
1974 Multinational Oil. New York:Macmillan.

Jodry, N.
1974 Unpublished estimate, cited in National Academy of Science (1975), Resources and Man. San Francisco:W.H. Freeman.

Joint Economic Committee, U.S. Congress
1975 "Adequacy of U.S. oil and gas reserves," Ninety-fourth Congress, 1st Session, February 25. Washington, D.C.:U.S. Government Printing Office.

Kaplan, N.
1965 "Professional scientists in industry," Social Problems 13:88-97.

Klemme, H.D.
1976 "World oil and gas reserves from analysis of giant fields and petroleum basins (provinces)," Pp. 217-260 in R.F. Meyer (ed.), The Future Supply of Nature Made Petroleum and Gas. New York:Pergamon.

Knebel, G.
1956 Unpublished estimate, cited in Hubbert (1962).

Knorr, K.
1981 The Manufacture of Knowledge. Oxford:Pergamon.

Knorr-Cetina, K.
1982 "Scientific communities or transepistemic arenas of research? A critique of quasi- economic models of science," Social Studies of Science 12:101-130.

Kolko, G.
1963 The Triumph of Conservatism: A Reinterpretation of American History, 1900- 1916. New York:Free Press.

Krueger, R.B.
1975 "U.S. policy past and present," Pp. 39-81 in Federal Energy Administration, The United States and International Oil. New York:Praeger.

Landsberg, H.H., L.L. Fischman, and J.L. Fischer.
1963 Resources in America's Future. Baltimore: Johns Hopkins University Press.

Langston, J.D.
1976 "A new look at the U.S. oil and gas potential," Pp. 33-50 in Exploration and Economics of the Petroleum Industry, Volume 14. New York: Matthew Bender.

Latour, B. and S. Woolgar
1979 Laboratory Life. Beverly Hills:Sage.

Linden, H.R.
1975 "Fossil fuel resources: Where do we stand?" Pipeline and Gas Journal 202(12):60-62,64-5.

Link, W.P.
1966 "An expert gives a geological approach to reserve ultimate of the U.S," Oil and Gas Journal 64(34):150-151.

Lovejoy, W.F. and P.T. Homan
1965 Methods of Estimating Reserves of Crude Oil, Natural Gas and Natural Gas Liquids. Baltimore:Johns Hopkins Press.

Lynch, Michael.
1979 Art and Artifact in Laboratory Science. Unpublished PhD. dissertation, Department of Sociology, University of California at Irvine.

Lynn,F.
1983 "Science and values in measuring risk: The impact of place of employment under conditions of uncertainty," Paper presented at 78th Annual Meeting, American Sociological Association, Detroit, August 31-September 4.

MacKenzie, D.
1981a Statistics in Britain, 1865-1930. Edinburgh:University of Edinburgh Press.

1981b "Notes on the science and social relations debate," Capital and Class 14:47-60.

MacNaughton, L.
1953 Economics of the Petroleum Industry. Albany: Bender.

Masters, C.
1979 "Recent estimates of U.S. oil and gas," Oil and Gas Journal, March 19, 1979: 151-162.

1979a Estimate reported by Thomas O'Toole, "U.S. oil resource estimate revised: Now 60 billion to 100 billion barrels," Washington Post, January 6, 1979:A4.

Mazur, A.
1981 The Dynamics of Technical Controversy. New York:Communications Press.

McAfee, J. and W. Davis
1964 "Crude surplus expected through 1975," Oil and Gas Journal 62(8):70-71.

McKelvey, V.
1966 "Reply to J.M. Ryan," Journal of Petroleum Technology 18:287.

1967 "Contradictions in energy resource estimates," Proceedings, 7th Biennial Gas Dynamics Symposium, The Technological Institute, Northwestern University, p.5-23.

1973 "Mineral resource estimates and public policy," Pp. 9-19 in D.A. Brobst and W.P. Pratt (eds.), U.S. Geological Survey Professional Paper Number 820. Washington D.C.:U.S. Government Printing Office.

1974 "U.S.G.S. releases revised U.S. oil and gas estimates," U.S. Department of Interior, News Release, March 26.

1975 "Concepts of reserves and resources," Pp. 11-14 in J.D. Haun (ed.), Methods of Estimating the Volume of Undiscovered Oil and Gas Resources. Tulsa:American Association of Petroleum Geologists.

McKelvey, V. and D.C. Duncan
1965 "United States and world resources of energy," Symposium on fuel and energy economics: American Chemical Society, Division of Fuel Chemistry 9(2):1-17.

Merton, R.
1938 Science, Technology and Society in Seventeenth Century England. 4(2):360-632 Bruges, Belgium: Saint Catherine Press.

1957 "Priorities in scientific discovery," American Sociological Review 22(6):635-59.

Miller, B.M., H.L. Thomsen, G.L. Dolton, et. al.
1975 Geological Estimates of Undiscovered Recoverable Oil and Gas Resources in the United States. United States Geological Survey Circular 725. Washington D.C.:U.S. Government Printing Office.

Miller, R.L.
1958 "A new look at ultimate natural gas reserves," World Oil 147(5):222-225.

Moody, J.
1970 "Petroleum demands of future decades," Bulletin of the American Association of Petroleum Geologists 54:2239-2245.

1974 Unpublished estimate, cited in R. Gillette (1974), "Oil and gas resources: Did the U.S.G.S. gush too high?" Science 185(7):127-130.

Moody, J.D. and R.W. Esser
1975 "An estimate of the world's recoverable crude oil resource," Proceedings, Nineth World Petroleum Congress, Tokyo, 3:11-20.

Moody, J. and R. Geiger
1975 "Petroleum resources: How much oil and where?" Technology Review 77(5):39-45.

Moore, C.
1962 "Method of Evaluating U.S. Crude Oil Resources and Projecting Domestic Crude Oil Availability," United States Department of Interior, Office of Oil and Gas, Washington D.C.

1966 "Projections of U.S. petroleum supply to 1980," U.S. Department of Interior, Office of Oil and Gas, Washington D.C.:U.S. Government Printing Office.

1970 "Analysis and projection of historic patterns of U.S. crude oil and natural gas," Pp. 50-54 in I.H. Cram (ed.), Future Petroleum Provinces of the United States--Their Geology and Potentail. American Association of Petroleum Geologists Memoir 15, Volume 1. Tulsa:American Association of Petroleum Geologists.

Mulkay, M.
1979 Science and the Sociology of Knowledge. London:Allen and Unwin.

1981 "The sociology of science in the West," Current Sociology 28(3):1-184.

Mulkay, M. and Gilbert, G. N.
1982a "Warranting scientific belief," Social Studies of Science 12(3):383-408.

1982b "Accounting for error: How scientists construct their social world when they account for correct and incorrect belief," Sociology 16(2):165-183.

1982c "What is the ultimate question? Some remarks in defence of the analysis of scientific discourse," Social Studies of Science 12(2):309-19.

Murrell, J.H.
1956 Estimate reported in Petroleum Week, March 16:9-14.

National Academy of Science-National Research Council
1975 Mineral Resources and the Environment. Washington D.C.:National Academy of Sciences.

National Energy Board
1969 Energy Supply and Demand in Canada and Export Demand for Canadian Energy, 1966 to 1990. Ottawa:National Energy Board.

1975 Canadian Oil Supply and Requirements Ottawa:National Energy Board.

1977 Reasons for Decision: Northern Pipelines Volumes 1-3. Ottawa:Supply and Services.

1978 Canadian Oil Supply and Requirements. Ottawa:National Energy Board.

1981 Canadian Energy Supply and Demand, 1980-2000. Ottawa:National Energy Board.

National Fuels and Energy Study
1962 "Report of the National Fuels and Energy Group on the assessment of available information on energy in the United States," U.S. Senate, Committee on Interior and Insular Affairs, 87 Congress, 2 Session, September 31. Washington D.C.:Government Printing Office.

National Petroleum Council
1970 Future Petroleum Provinces of the United States. Washington D.C.:National Petroleum Council.

1971 U.S. Energy Outlook 1971-1985: Preliminary Report. Washington D.C.:National Petroleum Council.

1973 U.S. Energy Outlook -- Oil and Gas Availability. Washington D.C.:National Petroleum Council.

Nash, G.
1968 United States Oil Policy 1890-1964. Pittsburgh:University of Pittsburgh Press.

Nehring, Richard and E.R. Van Driest II.
1981 The Discovery of Significant Oil and Gas Fields in the United States. Santa Monica, California:Rand Publishing.

Netschert, B.
1958 The Future Supply of Oil and Gas. Baltimore:Johns Hopkins.

Oil and Gas Journal
1957 "Drillers can look to a bright future," Oil and Gas Journal 55(42):68-70.

1958 "What is productive capacity?" Oil and Gas Journal 56(20):112-114.

1963a "We've found half the oil, says Hubbert," January 21:48-50.

1963b "U.S. reserves put at 600 billion bbl," September 2:78-79.

Oilweek
1972 "Canada has 80 cents advantage," Oilweek 23(1):79.

Parent, J.D. and H.R. Linden
1974 A Survey of United States and Total World Production, Proved Reserves and Remaining Recoverable Resources of Fossil Fuels as of December 31, 1972. Chicago:Institute of Gas Technology.

1977 A Survey of United States and Total World Production, Proved Reserves and Remaining Recoverable Resources of Fossil Fuels and Uranium as of December 21, 1975. Chicago:Institute of Gas Technology.

Parsons, T. and G. Plett.
1973 The American University. Cambridge: Harvard University Press.

Peach, H. G.
1982 "Social organization and the manufacture of statistical products," Paper presented at 7th Annual Meeting, Society for the Social Study of Science, Philadelphia, October 28-31.

Peltz, D. and F. Andrews
1966 Scientists in Organizations. New York: Wiley.

Pennebaker, P. E.
1972 "Vertical net sandstone determination for isopach mapping of hydrocarbon reservoirs," The American Association of Petroleum Geologists Bulletin 56(8):1520-1529.

Penrose, E.
1976 "The development of crisis," Pp. 39-48 in R. Vernon (ed.), The Oil Crisis. New York:Norton.

Perrow, C.
1979 Complex Organizations: A Critical Essay. Glenview, Illinois:Scott, Foresman and Company.

Petroleum Week
1956 "Is oil nearing a production crisis?" Petroleum Week, March 16:9-10.

Pfeffer, J. and G.R. Salancik
1978 The External Control of Organizations: A Resource Dependence Perspective. New York: Harper and Row.

Pinch, Trevor.
1982 "The Development of Solar Neutrino Astronomy," Unpublished PhD. dissertation, Department of Sociology, University of Bath.

Pogue, J.
1946 Unpublished estimate, cited in J.D. Moody, "Pogue places future oil finds at 490 billion barrels," Oil and Gas Journal 45(13):59.

Pogue, J. and K. Hill
1956 "Future growth and financial requirements of the world petroleum industry," New York:Chase Manhattan Bank, Petroleum Department. Presented at the annual meeting of the American Institute of Mining, Metallurgical and Petroleum Engineers, Petroleum Branch, February 26, 1956.

Pratt, W.E.
1942 Oil in the Earth. Topeka:Kansas University Press.

1945 "The earth's petroleum resources," Pp.137-153 in L.M. Fanning (ed.), Our Oil Resources. New York: McGraw-Hill.

1951 "On the estimation of undiscovered oil reserves," Journal of Petroleum Technology 3(4):9-10.

1956 Unpublished estimate, cited in "Impact of the peaceful uses of atomic energy on the coal, oil and natural-gas industries," Background material for the report of the panel on the impact of the peaceful uses of atomic energy to the Joint Committee on Atomic Energy, Vol. 2(January):94 Washington D.C.

Priebe, P. and G. Kauffman
1980 "Making government policy under conditions of scientific uncertainty: A century of controversy about saccharin in Congress and the laboratory," Minerva 18:556-74.

Rapp, D.
1975 "Estimation of the degree of advancement of petroleum exploration in the United States," Energy Sources 2(2):125-164.

Robbins, D. and R. Johnston
1976 "The role of cognitive and occupational differentiation in scientific controversies," Social Studies of Science 6:349-368.

Root, D.H. and E.D. Attanasi
1980 "World petroleum resource estimates and production forecasts: Implications for government policy," Natural Resources Forum 4:181-196.

Rustow, D.
1982 Oil and Turmoil: America Faces OPEC and the Middle East. New York:Norton.

Ryan, J.M.
1965 "Limits of logistic projections," American

Association of Petroleum Geologists Bulletin 49(10):1713-1720.

1966 "Limitations of statistical methods for predicting petroleum and natural gas reserves and availability," Journal of Petroleum Technology 18:281-284.

Ryman, W.P.
1967 Unpublished estimate, cited in M.K. Hubbert, "Degree of advancement of petroleum exploration in the United States," American Association of Petroleum Geologists Bulletin 51:2207-2227. (World estimates by Ryman, cited in Hubbert 1971).

Sampson, A.
1975 The Seven Sisters. New York:Bantam.

Saxe-Fernandez, J.
1980 Petroleo y Estrategia: Mexico y Estados Unidos en el Contexto de la Politica Global Mexico, D.F.:Siglo Veintiuno.

Schanz, J.J.
1975 "Problems and opportunities in adapting U.S. Geological Survey terminology to energy resources," Pp. 85-120 in M. Grenon (ed.), First IIASA Conference on Energy Resources Laxenburg, Austria: International Institute for Applied Systems Analysis.

1978 "Oil and gas resources: Welcome to uncertainty," Resources, Number 58 (March) Resources for the Future.

Schultz, P.R.
1952 "What is the future of petroleum discovery?" Oil and Gas Journal 51(12):258-259,295-300.

Schultz, T.
1979 "Distortions in economic research," Minerva 79:460-68.

Schurr, A.H., B. Netschert, et. al.
1960 Energy in the American Economy, 1850-1975. Baltimore:Johns Hopkins Press.

Schweinfurth, S.
1969 "Potential mineral resources of the United States continental shelf," Appendix in Public Land Law Review Commission Study of Outer Continental Shelf Lands of the United States, Vol. 4. Available from Natl. Tech. Info. Service, U.S. Department of Commerce.

Scott, W.R.
1981 Organizations: Rational, Natural and Open Systems. Englewood Cliffs, N.J.:Prentice- Hall.

Shaffer, A.
1983 Canadian Oil and the American Empire. Edmonton:Hurtig.

Shapin, S.
1975 "Phrenological knowledge and the social structure of early nineteenth-century Edinburgh," Annals of Science 32:219-243.

1979 "The politics of observation: cerebral anatomy and social interests in the Edinburgh phrenology disputes," Pp. 139- 178 in R. Wallis (ed.), On the Margins of Science. Stratfrodshire:University of Keele.

1982 "The history of science and its sociological reconstructions," History of Science 20:157-211.

Sheldon, R.P.
1975 "Estimates of undiscovered petroleum resources -- a perspective," United States Geological Survey Annual Report Fiscal Year 1975 Pp. 11-22.

Shell Oil Company
1967 Energy Patterns of the Future. Shell Briefing Service, Royal Dutch Shell Group.

1975 Estimate cited byStannage (1979:114).

1978 "Shell: Alaska holds 58% of future U.S. oil finds," Oil and Gas Journal, November 20, 1978:214.

Sherrill, R.
1974 "The old shell game," Penthouse, October 42-45, 89-91.

Shils, E.
1979 "Governments, foundations and the bias of research," Minerva 79:459.

Smil, V. and W. Knowland (eds.)
1980 Energy in the Developing World: The Real Energy Crisis. Oxford:Oxford University.

Stannage, W.
1979 "Resource estimates and politics don't mix," World Oil 189(5):113-116,118.

Stern, J.
1982 East European Energy and East-West Trade in Energy. London:British Institute.

Stoff, M.
1980 Oil, War and American Security. New Haven:Yale University Press.

Swafford, M.
1980 "Three parametric techniques for contingency table analysis: A nontechnical commentary," American Sociological Review 45:664-90.

Swatez, G.
1970 "The social organization of a university laboratory," Minerva 8(1):36-58.

Tanner, William F.
1978 "Future oil: What is the outlook?" World Oil, 187(6):123-140.

Tanzier, M.
1969 The Political Economy of International Oil and the Underdeveloped Countries. Boston:Beacon.

Theobald, P.K., S.P. Schweinfurth and D.C. Duncan.
1972 Energy Resources of the United States. United States Geological Survey Circular 650. Washington D.C.:U.S. Government Printing Office.

Uri, N.D.
1979 "New look at U.S. reserves shows higher potential," World Oil, February 1, 1979:61.

1980 "Estimating undiscovered oil resources: An engineering approach," Energy Sources 5(3):197-209.

U. S. Department of Interior
1956 Unpublished estimate, cited in "Impact of the peaceful uses of atomic energy on the coal, oil and natural-gas industries," Background material for the report of the panel on the impact of the peaceful uses of atomic energy to the Joint Committee on Atomic Energy, Vol. 2(January):94 Washington D.C.:Government Printing Office.

1962 Energy Policy, Supplies, Costs and Uses of the Fossil Fuels. Study prepared for the Atomic Energy Commission (Washington D.C., June 1962).

1972 U.S. Energy--A Summary Review. Washington D.C.:U.S. Government Printing Office

Vernon, R.
1976 The Oil Crisis. New York:Norton.

1983 Two Hungry Giants. Cambridge:Harvard University.

Warren, R.L.
1967 "The interorganizational field as a focus of investigation," Administrative Science Quarterly, 12(4):396-419.

Weeks, L.
1948 "Highlights on 1947 developments in foreign petroleum fields," Bulletin of the American Association of Petroleum Geologists 32:1093-1160.

1958 "Fuel reserves of the future," Bulletin of the American Association of Petroleum Geologists 42(2):434-443.

1959 "Where will energy come from in 2059?" The Petroleum Engineer 31(8):A24-A31.

1965 "World offshore petroleum resources," Bulletin of the American Association of Petroleum Geologists 49(10):1680-93.

1966 "Estimation of petroleum resources," American Association of Petroleum Geologists Bulletin 50(9):2008-2010.

Weinberg, A.
1967 Reflections on Big Science. Cambridge: MIT Press.

West, J.
1974 "U.S. oil policy riddle: How much left to find?" Oil and Gas Journal 72(37):25-28.

White, D.A. and H.M. Gehman
1979 "Methods of estimating oil and gas resources," Bulletin of the American Association of Petroleum Geologists 63(12):2183-2192.

Wildavsky, A. and E. Tanenbaum
1981 The Politics of Mistrust: Estimating American Oil and Gas Resources. Beverly Hills, Calif.:Sage.

Wiorkowski, J.J.
1981 "Estimating volumes of remaining fossil fuel resources: A critical review," Journal of the American Statistical Society 76(375): 534-548.

Williamson, H.F., R.L. Andreano, et.al.
1959- The American Petroleum Industry.
1963 Volume 1: The Age of Illumination.
Volume 2: The Age of Energy. Evanston, Ill.:Northwestern University Press.

Woolgar, S.
1981a "Interests and explanation in the social study of science," Social Studies of Science 11:365-94.

1981b "Critique and criticism: two readings of ethnomethodology," Social Studies of Science 11:504-14.

Yearley, S.
1982 "The relationship between epistomological and cognitive interests: Some ambiguities underlying the use of interest theory in the study of scientific knowledge," Studies in the History and Philosophy of Science 13(4):353-388.

Zald, M.N.
1970 "Political economy: A framework for comparative analysis," Pp. 221-261 in M.N. Zald (ed.), Power in Organizations. Nashville:Vanderbilt University Press.

Zapp, A.
1962 Future Petroleum Producing Capacity in the United States. United States Geological Survey Bulletin 1142-H. Washington D.C.:U.S. Government Printing Office.

APPENDIX I

ADJUSTMENTS MADE TO ESTIMATES

This appendix locates the estimates utilized in this thesis and documents the adjustments made to some of them. These adjustments were of four major types. First, if the estimates were for total liquid hydrocarbons rather than for crude oil, following Hubbert (1962) and others, a conversion factor of 85 percent was applied. Second, if the estimates were for future supplies, then the estimates were adjusted to include proven reserves and/or past production. Third, if the estimates included Alaska and no indication of the amount attributable to that area was given, then, following the consensus evident in 1974-5 (Gillette, 1974; American Academy of Science, 1975), 45 billion barrels was attributed to that area and subtracted from the estimate. Fourth, if no indication of a mean value was given, then the midpoint of the range was used to arrive at a point estimate.

Pratt (1942:47)
    100 billion barrels (Bbls) minimum
Pratt (1945:125)
    100 Bbls minimum
Weeks (1948:1094)
    110 Bbls
Pratt (1950, cited by Stannage, 1979:114)
    142 Bbls
Schultz (1952:259)
    200 Bbls minimuum
MacNaughton (1953, cited by Hubbert 1962:47)
    200 Bbls
Ayres (1955:20)
    140 Bbls
Murrell (1956, cited in Petroleum Week, 1956:9)
    200 Bbls
Pratt (1956:94)
    170 Bbls total liquid hydrocarbons x 0.85 =
    145 Bbls crude oil
Hubbert (1956:18)
    175 Bbls (midpoint of 150-200 BBl range)
Pogue and Hill (1956:24)
    165 Bbls
Knebel (1956, cited by Hubbert, 1962:47)
    203 Bbls total liquid hydrocarbons x 0.85 =
    173 Bbls crude oil

U.S. Department of Interior (1956:82)
300 Bbls
Company A (1957, cited in Oil and Gas Journal 1957:70)
150 Bbls
Company B (1957, cited in Oil and Gas Journal 1957:70)
300 Bbls (midpoint of 250-350 Bbl range)
Company C (1957, cited in Oil and Gas Journal, 1957:70)
200 BBls
Company D (1957, cited in Oil and Gas Journal, 1957:70)
300 BBls
Company E (1957, cited in Oil and Gas Journal, 1957:70)
310 Bbls minimum
Company F (1957, cited in Oil and Gas Journal, 1957:70)
325 Bbls
Hill, Hammer and Winger (1957:26)
250 Bbls minimum
Oil and Gas Journal (1958:112)
300 Bbls
Weeks (1958:434)
240 Bbls total hydrocarbons x 0.85 = 204 Bbls crude oil
Miller (1958:222-223)
250 Bbls (midpoint of 200-300 Bbl range)
Davis (1958:114)
165 Bbl
Netschert (1958:24,55)
500 Bbls resource base x 0.67 recovery + 57 Bbls past production = 390 Bbls.
Coqueron, Hammer and Winger (1958)
250 Bbls
Weeks (1959:25)
460 Bbls total hydrocarbons x 0.85 = 391 Bbls crude oil
Averitt (1961:100)
470 Bbls total hydrocarbons x 0.85 = 400 Bbls crude oil
Hubbert (1962:60)
170 Bbls
Hubbert (1962:72)
175 Bbls
Moore (1962:8)
364 Bbls
Zapp (1962, imputed by Hubbert 1962:48-9)
590 Bbls
National Fuels and Energy Group (1962, cited by Hubbert, 1978:12)
457 Bbls (midpoint of 407-507 range)
U.S. Geological Survey (1963, cited in Oil and Gas Journal, 1963b:78)
600 Bbls
Ion (1963:112)
275 Bbls
McKelvey and Duncan (1963, cited in Hendricks 1965:3)

588 Bbls + past production = 658 Bbls

Landsburg (1963:393)

290 Bbls (midpoint of 250-330) + past production = 360 Bbl

McAfee and Davis (1964:71)

275 Bbls

McKelvey and Duncan (1965, cited by Hubbert 1978:13)

656 Bbls

Hendricks (1965:12)

400 Bbls - 45 Bbls in Alaska = 355 Bbls

Weeks (1965:1686)

270 Bbls

Hubbert (1966:286)

170 Bbls

Link (1966:151)

240 Bbls

Moore (1965, cited by Ryan, 1966:282)

300 Bbls

Hendricks and Schweinfurth (1966, cited in U.S. Department of Interior, 1968:11)

500 Bbls - 45 Alaska = 455 Bbls

Hubbert (1967:2224)

170 Bbls

Ryman (1967, cited by Hubbert, 1969:194)

200 Bbls

Elliot and Linden (1968:138)

450 Bbls

Hubbert (1969:193)

165 Bbls

Schweinfurth (1969)

450 Bbls - 45 Alaska = 405 Bbls

National Petroleum Council (1970, cited by Linden, 1975:61)

339 Bbls + 90 Bbls past - 45 Bbls Alaska = 384 Bbls

Moore (1970:51)

353 Bbls

Arps, Mortada and Smith (1971:674)

165 Bbls

Hubbert (1971:65)

200 Bbls - 40 Alaska = 160 Bbls

National Petroleum Council (1971:34)

677 Bbls ultimately discoverable x 0.40 recovery factor = 271 Bbls

Cram (1971:25)

305 Bbls - 45 Bbls Alaska = 260 Bbls

Jodry (1972, cited in Stannage, 1979:114)

190 Bbls

U.S. Department of Interior (1972, cited by Cook, 1975:98)

549 Bbls - 45 Bbls Alaska = 504 Bbls

Theobald, et. al. (1972:7)

502 total hydrocarbons x 0.85 = 427 Bbls crude oil

+ 96 past production = 523 Bbls
Schweinfurth (1973, cited in Albers, et. al. 1973:116)
600 Bbls - 45 Alaska = 555 Bbls
Hubbert (1973:48)
175 Bbls
National Petroleum Council (1973, cited by Energy and and Resources Planning Group, 1981:24)
154 Bbls undiscovered liquid hydrocarbon x 0.85 = 131 Bbls crude oil + 152 Bbls past, proven and inferred - 45 Bbls Alaska = 238 Bbls
Bonillias (1973, cited by Stannage, 1979:114)
300 Bbls - 45 Bbls Alaska = 255 Bbls
Hubbert (1974:123)
172 Bbls
Moody (1974, cited in Gillette 1974:128)
47 Bbls undiscovered liquid hydrocarbons x 0.85 = 40 Bbls + 159 Bbls past, proven and inferred = 199 Bbls
Jodry (1974, cited as Company E in National Academy of Science, 1975:89)
90 Bbls undiscovered liquid hydrocarbons x 0.85 = 76.5 Bbls + 159 Bbls past, proven and inferred - 45 Bbls in Alaska = 200 Bbls
McKelvey (1974, reprinted in Hubbert 1974:363-367)
300 Bbls undiscovered liquid hydrocarbons (midpoint of 200-400 range) x 0.85 = 255 Bbls crude oil + 159 Bbls past, proven and inferred - 45 Alaska = 369 Bbls
Berg (1974:332)
400 Bbls - 45 Alaska = 355 Bbls
Ford Foundation (1974, cited by Cook, 1975:98)
628 Bbls - 45 Alaska = 583 Bbls
Exxon (1975, cited by Stannage, 1979:114)
261 Bbls - 45 Bbls Alaska = 216 Bbls
Moody and Geiger (1974:39,40)
230 Bbls - 40 Bbls Alaska = 190 Bbls
Moody and Esser (1975, cited by Energy and Resource Planning Group, 1981:24)
85 Bbls undiscovered crude oil + 157 Bbls past, proven and inferred - 45 Bbls Alaska = 197 Bbls
Miller (1975:29)
206 Bbls
National Academy of Sciences (1975:90)
113 Bbls undiscovered liquid hydrocarbons x 0.85 = 96 Bbls crude oil + 160 Bbls proved, past and inferred - 45 Bbls Alaska = 211 Bbls
Shell (1975, cited by Stannage, 1979:114)
253 Bbls - 45 Bbls Alaska = 208 Bbls
Rapp (1975:162)
170 Bbls
Rapp (1975:163)

163 Bbls
Rapp (1975:163)
155 Bbls
Bromberg and Hartgan (1975, cited by Wiorkowski, 1981:546)
70 Bbls undiscovered + 130 Bbls proved, past +
15 Bbls offshore = 215 Bbls
Grossling (1976:104)
216 Bbls + 15 offshore = 231 Bbls
Langston (1976:40)
163 Bbls future liquid hydrocarbons x 0.85 =
139 Bbls crude oil + 109 Bbls past production -
45 Bbls Alaska = 203 Bbls
Fowler (1977:189)
154 Bbls
Tanner (1978:136)
179 Bbls
Tanner (1978:136)
166 Bbls
Shell (1978, cited in Oil and Gas Journal, 1978:214)
25 Bbls undiscovered + 167 past, proved and inferred =
192 Bbls
Masters (1979, cited in O'Toole, 1979:A4)
80 Bbls (midpoint of 60-100) + 172 past, proved and
inferred - 45 Bbls Alaska = 207 Bbls
Hubbert (1979:?)
163 Bbls
Halbouty and Moody (1979:298)
238 Bbls - 45 Alaska = 193 Bbls
Parent (1979:56)
291 Bbls (midpoint of 259-324 range) - 45 Bbls
Alaska = 246 Bbls
Uri (1978, cited in World Oil, 1979:61)
198 Bbls
Uri (1980:208)
198 Bbls
Nehring (1981:168)
181 Bbls
Wiorkowski (1981:547)
161 Bbls + 15 Bbls offshore = 176 Bbls
Mayer (1981, cited by Schuenemeyer, 1981:556)
150 Bbls + 15 offshore = 165 Bbls
Mayer (1981, cited by Schuenemeyer, 1981:556)
150 Bbls + 15 Bbls offshore = 165 Bbls
Mayer (1981, cited by Schuenemeyer, 1981:556)
175 Bbls + 15 Bbls offshore = 190 Bbls
Dolton, et. al. (1981:2)
223 Bbls
Cargill (1981)
213 Bbls