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DISCONTINUOUS TECHNOLOGICAL CHANGE AND INSTITUTIONAL LEGITIMACY: A MORPHOLOGICAL PERSPECTIVE

A Dissertation
Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

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ABSTRACT

Technological innovation is an important consideration to many strategic managers and thus is important to research in Strategic Management. Deepening the field's understanding of what technology is and how it works can be facilitated by participating in a growing dialogue between the Strategic Management and Management of Technology communities. This dissertation considers elements of both fields and examines the premise that at the industry level, incumbents act to manipulate the "share of mind" or "cognitive legitimacy" of the performance and cost/price characteristics of product-technology innovations that, in aggregate, portend to either enhance or destroy prevailing industry competences. A forecasting technique well-known to technological communities (Morphological Analysis) is used to dissect technologies and competences, dimensionalize competence enhancement and destruction, and test hypotheses. Major findings suggest that: Morphological Analysis has great potential as a tool for aiding academic research in technological change; technologies were evolving in the chosen industry much as the Strategic Management and Management of Technology literatures predicted; and in the experimental setting, the depiction of this evolution in the public media showed a bias towards newsworthiness, but otherwise portrayed the new industry activity accurately. However, interpretations suggested that one phenomenologically distinct technological trajectory was likely to become established in the short-term, despite the finding that this trajectory was not necessarily the most rational socioeconomic choice.

CHAPTER 1: INTRODUCTION

In recent years, it has become clear to many types of researchers that innovation is important to the success of many types of businesses (Baden-Fuller & Stopford, 1994; Betz, 1987; Betz, 1993; Burgelman & Sayles, 1986; Freeman, 1994; Freeman, 1990; Kanter, 1983; Marceau, 1994; Pinchot, 1985; Roberts, 1991). Some of them (Betz, 1987; Burgelman & Sayles, 1986; Freeman, 1994; Marceau, 1994) have helped resurrect and promote the contributions of earlier philosopher-economists (Rostow, 1990) who noted the impact that technological innovation, in particular, has had on firm success, industry evolution and revolution, and general economic growth and prosperity. While Strategic Management researchers generally recognize that innovation is an important strategic issue, they have not paid a great deal of attention to the endogenous role of technology. At least part of the explanation of why technology is rarely considered to be more than a "functional" element of corporate or business strategy, or a dimension of the macroenvironment, lies in an understanding of how Strategic Management developed as a field of study.

Strategic Management owes most of its pedigree to several broad research traditions: Industrial Organization (and Neoclassical Economics in general), Marketing, and Administrative Behavior (Organizational Behavior, Organizational Theory, Psychology, and Political Science) (Barney & Zajac, 1995; Jemison, 1981). The impact of Economics (Aubretsch, 1995; Porter, 1985; Tirole, 1990) has possibly been the most profound, but its treatment of technological innovation and change has usually been problematic (Sake, 1994). For example, traditional production functions are often used to help explain technological innovation (Carlsson, 1994), but such depictions are highly abstract and do not clearly distinguish economic from technical factors (Goodman and Lawless, 1994). Alternatively, sometimes technological innovation is operationalized as a "Pythagorean count" such as number of patents, but measures like this are known to be rather weak proxies for what technology is at its heart (Aubretsch, 1995; Lissoni & Metcalfe, 1994; Sahal, 1981). Overall, the economics view of technological innovation and change is friendly to evolution but fundamentally antithetical to revolution (Goodman & Lawless, 1994). To the extent that Strategic Management has adopted the views of mainstream economics, then, its view of technological innovation would seem to be similarly problematic (Coombs, 1994; Bijker, 1995; Marceau, 1994). Porter's (1980) five forces model, for example, has been criticized as being inadequate under conditions of instability, radical change, or hypercompetition. It has been necessary to develop concepts like "punctuated equilibrium" (Gersick, 1991) to help account for these conditions, as if they were anomalous.

Technological innovation is important to the Marketing tradition, as it is often the genesis of both product and service differentiation (Abell, 1980; Zeithaml, Parasuranam, & Berry, 1985). However, its impact on Strategic Management in this area also shows limitations. First, enamoration with the customer/consumer is somewhat deterministic, simultaneously inspiring and constraining innovation (Littler, 1994; Utterback, 1994). That is, the importance of being "close to the customer" notwithstanding, consumers are often myopic to truly innovative possibilities, at least where product technologies are concerned. Second, and relatedly, research in Marketing has largely avoided the technology-development problem in and of itself (Davidow, 1986; Page & Rosenbaum, 1988; Shanklin & Ryans, 1988). Marketing certainly appreciates the strategic need to coordinate with technologists (especially the R&D function), and does not shy away from high technology products per se . But while Marketing has impressively championed the "market pull" view of technological innovation, it has left the "technology push" view and associated issues to other disciplines (like R&D Management and Engineering). Whether or not Marketing's focus has been appropriate to its natural domain, the point is that Strategic Management has inherited a mostly user-oriented view of technology from that field.

The study of Administrative Behavior has made important contributions to understanding the organizational dynamics of innovation. The consensus seems to be that innovation is affected by static organizational characteristics like structure/size and formalization/centralization; dynamic organizational characteristics like communications, planning and decision-making; and relatively intangible organizational characteristics like climate and culture (Imperato & Harari, 1995; Katz, 1988; Nadler et al., 1995). In this view, however, management's influence on innovation seems somewhat removed. The message is that innovation is a spontaneous, probabilistic occurrence, and therefore management's greatest contribution lies in its ability to establish innovation-conducive conditions. More to the point, what is conspicuously absent is a focused and in-depth treatment of the development of new technologies. In the main, then, it seems as if Strategic Management scholars have demurred the problem of developing new technologies, as a major concern, to other disciplines.

This situation might be interpreted in one of two ways. One, it might be assumed that as Strategic Management has evolved, it has adopted parts of other disciplines -- theories, models, and constructs -- and developed an eclectic quasi-paradigm of its own that understands technological innovation to be the natural outcome of good (or simply other types of) management (Granstrand & Sjolander, 1994). The second possibility is that due to the specific individual foci of its intellectual benefactors, the Strategic Management synthesis has always lacked the vehicle by which technological innovation could be considered as centrally important (Coombs, 1994). Either way, it is difficult for a Strategic Management researcher to focus on the strategic importance of technological innovation from the standpoint of that discipline's richer traditions.

Fortunately, the rapidly developing Resource/Competence-based perspective is very accommodating in this regard. In general, advocates of this broad perspective hold that organizational capabilities, resources, and other firm-specific assets affect competitive advantage (Barney, 1991; Grant, 1991; Peteraf, 1993; Schendel, 1994; Wernerfelt, 1984). In particular, Hamel and Prahalad (1994) have developed a framework that is intentionally designed to transcend the blinders that market/industry "structure" models often impose. They have advocated a truly long-term view designed to help find, develop and match an organization's "core" competence with broadly defined functional needs. This invites the technological innovation issue into the Resource/Competence-based perspective for a very simple, but consistently overlooked reason. In contrast to neoclassical economics' materialistic operationalizations of technology, and in contrast to Marketing's end-user bias, and in contrast to Administrative Behavior's abstractions, it is a common understanding in other scholarly communities that technology is first and foremost human-based competence (Betz, 1993). Specifically, technology is not simply the <u>result</u> of competence; technology <u>is</u> competence. Accepting this definition is to also adopt the Resource/Competence perspective of Strategic Management.

In other words, the competence(s) that is(are) are needed to translate basic scientific knowledge into problem-solving functionality is(are) potentially the source(s) of sustained competitive advantage. Naturally, firms that hold such advantages are motivated to protect and enhance them, while their present and future competitors are motivated to attack and destroy them (Grandstrand & Sjolander, 1994; Pavitt, 1994). Where innovation is concerned, firms already possessing competitively advantageous technologies (typically industry incumbents) are motivated to make "competence-enhancing" innovations, or innovations which build on existing expertise and make the innovating firms stronger (Anderson & Tushman, 1990; Faitlough, 1994; Tushman & Anderson, 1986; Utterback, 1994). Firms that do not possess technologies that are presently competitively advantageous are motivated to make "competence-destroying" innovations, or innovations that are different in ways that, when successful on large scales, force incumbents to either make massive investments of many types or suffer the consequences of obsolescence. At the industry level, and especially in mature industries, competence-enhancing innovations create and/or strengthen existing entry barriers; competence-destroying innovations lower, destroy, and/or re-create such barriers. At issue, then, is long-term industry survival, rejuvenation, or replacement.

Competence enhancement and destruction are highly related (but not perfectly analogous) to two other concepts: incremental and discontinuous technological change (Betz, 1987). An incremental technological change is a small improvement in an existing technology, while a discontinuity is a conscious switch from the use of one technology to the use of another. For example, it is common folklore that Thomas Edison toiled for many years experimenting with different materials in order to both invent, and then continuously improve the efficiency of, both incandescent light bulbs and a publicly accessable infrastructure of Direct-Current (DC) electric power. Eventually, however, even Edison's incremental tenacity was obviated by his arch-rival George Westinghouse, who developed a much more sophisticated and efficient system by exploiting Alternating-Current (AC) technology (Butts & Grimm, 1994). Incremental and discontinuous changes can be graphically depicted rather simply when guided by a general understanding of technology s-curves, but competence enhancement and destruction are technologically, sociologically, and economically much more complex. Case in point: both competence-enhancing and competence-destroying technological discontinuities occur, but most research has been able to distinguish the two only through historical analysis (Utterback, 1994).

Statement of the Problem

It is safe to assert that one of Strategic Management's more enduring goals is the development of theories and models that improve strategic business decisions aimed at improving long-term organizational performance (Summer et al., 1990). Here, historical accounts of industrial change brought about by technological discontinuities have important value, in that descriptions of the past can serve as analogies to present problems. But in terms of Strategic Management's underlying norm, the real issue is technological forecasting, which in the case of discontinuities has been described as complex to impossible (Tushman & Anderson, 1986; Betz, 1993). Given enough data, the past can usually be described and understood; but scholars agree that regardless of our appreciation of history, the prediction of discontinuities will continue to be troublesome.

Considering the gravity of the issue, any improvement in managing discontinuities proactively would be an important contribution (Prahalad & Hamel, 1994). To begin, it is important to observe that R&D and Engineering researchers and practitioners have, for many years, struggled to develop tools and techniques that can be used to help forecast technological change (Twiss, 1988). They agree that accurate prediction is difficult-to-impossible, but have made important progress in terms of being able to forecast likely paths and trajectories. Of keen interest here is the technique, ubiquitous in R&D communities, called Morphological Analysis (Ayres, 1969; Betz, 1993). A fundamental advantage of this technique is that it enters the "black box" of technology in an extraordinarily objective way. It views a product (however simple or complex) as a collection of natural (i.e., naturally occurring, or governed by natural "law") phenomena (and knowledge thereof), or as a consciously manipulated coordination of natural occurrences. The immediate advantage to the forecaster is that Morphological Analysis is unconstrained by prevailing socio-economic structures and shortsighted biases. An additional advantage, and one that is key to the present problem, is that is has conceptual links to discontinuities. In short, Morphological Analysis can be used as an aid in the ostensibly impenetrable problem of forecasting discontinuities.

Naturally, the next issue is how to apply the objectivity offered by Morphological Analysis amid the complexities of socioeconomic dynamism. Earlier it was stated that in Hamel and Prahalad's (1994) view, accepting existing market and industry structures as given is to unnecessarily limit one's ability to foresee other possibilities. Considering that the main issue is that technological discontinuities do, in fact, sometimes change these structures, changes among them should be considered in an accommodating theoretical framework. To be specific, it is reasonable to assert that if an industry is to be transformed (via competence destruction) by a discontinuous technological innovation, the new technology must achieve a certain level of "cognitive legitimacy" in society at large (Aldrich & Fiol, 1994). The more radical the innovation, the higher is this hurdle of cognitive legitimacy. Since established technologies have already achieved a high level of cognitive legitimacy, incremental improvements to them face a relatively low level of resistance to change in the marketplace. Discontinuous changes, especially those which threaten to change lifestyles or broad socioeconomic infrastructures, face much higher levels of resistance. The battle for new markets, industry definition, and a sustainable long-term position is first and foremost the battle for cognitive legitimacy -- or what Hamel and Prahalad (1994) called "share of mind."

The key problem, then, is this: Faced with the possibility of competence-destruction on an industrial scale, and armed with the fundamental ability to foresee general technological trends and trajectories, how do industry incumbents attempt to shape the cognitive legitimacy of existing and radically new technologies?

Significance of the Study

The main purpose of this study is to contribute to the development of a view and associated technique by which practitioners and researchers can make real-time assessments of discontinuous technological changes and associated strategic responses. As implied, improvement over historical retrospection requires that the problem be broken down into two fundamental parts: determination of technological trends and accompanying competences; and an empirical examination of the proactive strategic responses that would be expected from profit-seeking firms.

In order to do a real-time assessment, it is most appropriate to identify a mature industry (and therefore a set of generally mature technologies), that is apparently on the verge of discontinuous change. In a mature industry, s-curves are likely to be near their peaks, which invites rejuvenation or replacement via discontinuous technological change. Here, a natural experiment is in progress. Existing California law requires that beginning in 1998, automakers that sell large numbers of autos in the state must make available a certain percentage of zero-emission vehicles. The movement has spread rapidly, has had strong federal support, and as of this writing similar legislation exists or is pending in other states that collectively account for 33% of all U.S. auto sales (Winn, 1994). The legislated penalties for failure will be severe, and the commercial consequences of success are difficult to accurately imagine. Here, electrically powered autos are the only viable solution; choices within that envelope, however, are diverse and complex. Without a doubt, the most limiting technological constraint is what is commonly, though somewhat inaccurately, described as the "battery" problem. In a nutshell, electric autos do not go very far on one "fill-up." Firms are experiencing great pain and expense as they try to write the technological rules of this new (or certainly changing) industry.

In order to assess this situation from the morphological perspective, a Morphological Analysis of the parameters that govern "batteries" will first be developed. This analysis will produce a matrix, or map, that will depict technological possibilities (and by definition, concomitant competences) along two general dimensions. In short, the argument is that natural law objectively dimensionalizes technology, technological competence, and the potential for enhancement or destruction in future competitive space.

The subcategories in each dimension will then be used as categorical predictors of several specific strategic responses that the literature implies incumbents are prone to make. Specifically, incumbents should be expected to make competence-enhancing innovations, while (potential) new entrants should be expected to make competence-destroying innovations. Each morphological dimension will be used to measure this prediction. Second, incumbents should be expected to defend existing competences by promoting their advantages, and likewise attack the disadvantages of potentially competence-destroying technologies. In short, competence-enhancing innovations have early performance and price advantages, while competence-destroying innovations have future performance and price advantages. (The advantages of one type of innovation are, by definition, the disadvantages of the other type.) At the nexus of potential industry renewal, the struggle is largely one for simple "cognitive legitimacy." The literature suggests that incumbents attempt to shape the cognitive legitimacy of their technologies through proactive information campaigns. As such, a structured content analysis of several thousand mass media extracts will be conducted to look for "legitimation" trends and biases.

This study will make several contributions. First, it will help extend an ongoing cross-disciplinary dialogue between the Strategic Management and Management of Technology communities. Aside from the inherent appeal of theoretical cross-fertilization, it has been well-established that technological innovation is one of the more important drivers of both strategic success and macroeconomic progress. Second, it will extend the ongoing development of the Resource/Competence-based view of Strategic Management. This view is relatively young, but widely acclaimed for its potential. Third, it will help diffuse into wider circles Morphological Analysis, a tool that has been available as a forecasting technique for almost fifty years. Fourth, it will contribute to an understanding of how to analyze technological discontinuities in real time. While doing so, however, it will respect the caveat that technology forecasting has proved to be an inherently frustrating undertaking. In this light, even small gains will be insightful. Finally, it will help extend an understanding of an important contemporary problem in a vital industry (Graves, 1994; Winn, 1994). Assuming that legislators continue their resolve, the electric automobile industry will emerge in some form. The locus of that emergence is not at all certain, and even global patterns are not yet clear.

Summary of Remaining Chapters

This introduction has framed a set of conditions and the choices they imply towards studying an important topic in an equally important context. Subsequent chapters review the relevant literature, generate specific propositions and hypotheses, propose a study design, present the results of tests and analyze their implications.

As the relevant literature comes from several research areas, Chapter 2 (Literature Review) is divided into segments. First, Strategic Management will be considered. Mintzberg's (in Frederickson, 1990) "ten schools" will be used as a framework for analyzing some of the relevant weaknesses in the field's main streams of thought. Second, a portion of the Management of Technology literature will be reviewed, showing the existence of models and frameworks that (a) consider technological innovation as centrally important, and (b) are directly applicable to the level of analysis that is of central concern to the business strategist. Third, the history, strengths, and weaknesses of Morphological Analysis will be reviewed, explicating some of its fundamental potentials and caveats. Fourth, Institutional Theory will be introduced as a correct perspective for assessing one important strategic concern, that being the legitimation of existing and emerging technologies.

In Chapter 3, the dimensionalization of technologies/competences in the morphological perspective is explained, and then propositions and hypotheses are developed by weaving together some of the plainer relationships among the major constructs presented in the literature review.

In Chapter 4, the design of the study is presented. A Morphological Analysis of electrochemical power sources is developed by following the "rules" explained in the literature. The resulting matrix was used as a baseline for testing the hypotheses. The sample, variables, measures, coding technique, and tests are also described.

In Chapter 5, results of testing the hypotheses are reviewed and discussed. Results of each test were statistically strong, though not always in the direction hypothesized. Contrasts among the major findings indicated the need for additional analysis before interpretation.

Chapter 6 provides additional tests of hypotheses under revised assumptions. Again, results were strong, indicating that Technology Cycles frameworks are powerful but that the public media was not substantially biased. Serendipitous findings indicated how various technological trajectories were developing, which had important implications regarding the development of socioeconomic and technoeconomic infrastructures.

Chapter 7 presents the implications of the results of all tests organized by each major body of literature. Limitations of the study are then discussed prior to summarizing implications for future research.

CHAPTER 2: LITERATURE REVIEW

The following literature review juxtaposes several bodies of literature in order to highlight several areas of mutual concern. First, the Strategic Management literature is reviewed, showing a conundrum faced by researchers interested in the importance of technology, and describing a recently developing solution to this conundrum. Second, a portion of the Management of Technology literature is reviewed, focusing on Technology Cycles and their importance to the Strategic Management point of view. Third, a portion of the R&D Management literature is reviewed, describing Morphological Analysis in depth and examining its potential as an academic research tool. Fourth, Institutional Theory is briefly reviewed, concentrating on how the cognitive legitimation of new technologies might occur. The chapter concludes by summarizing the main points and suggesting an important research question.

Strategic Management

In 1942, economist Joseph Schumpeter (Schumpeter, 1976) articulated a basic view of economic growth that grappled with a problem that had perplexed economists since Adam Smith: how to consider technological change as an endogenous variable in a model of macroeconomic development (Rostow, 1990). While lionizing the impact of the individual entrepreneur, he asserted that technological innovation is the principal engine of capitalism's constant rejuvenation; that economic equilibria are always being displaced by incremental changes in existing technologies and, more famously, by spontaneous and discontinuous innovations. This latter dynamic he described as "creative destruction," a term which has since become common and which has received significant empirical support (Fellner, 1970; Freeman, 1994; Nelson, 1993; Rothwell, 1994; Schmookler, 1965; Solow, 1957; Steinmueller, 1994; Villard, 1958):

> Creative Destruction is the essential fact of capitalism ... [capitalism] can not be understood irrespective of it, or, in fact, on the hypothesis that there is a perennial lull ... the problem that is usually being visualized is how capitalism administers existing structures, whereas the relevant problem is how it creates and destroys them. As long as this is not recognized, the invesitigator does a meaningless job (Schumpeter, 1976: 83-4).

However, Schumpeter's work fell short of being a full theory, and despite important progress made by other scholars, mainstream economics has generally maintained its dependence on models that assume equilibration, not creative destruction (Carlsson, 1994; Freeman, 1994; Lissoni & Metcalfe, 1994; Rostow, 1990). This description is not made to disparage the study of Economics, but to suggest a partial explanation of why the study of Strategic Management (which depends on Economics for much of its theoretical foundation) maintains a similar view of technological change. As Strategic Management is an eclectic field, however, it is difficult to identify "the" strategic paradigm; a totally comprehensive literature review, therefore, would be unnecessarily exhausting. The main point can be illustrated succinctly by reviewing the most dominant approaches to Strategic Management. Mintzberg (in Frederickson, 1990) has provided an adequate framework in his evaluation of the field's "ten schools."

First, several of these schools are at most tangentially concerned with technology. In the Design school, epitomized by Selznick's (1957) emphasis on leadership and organizational purpose, technological change is at best implied. In Andrews' view (1987), technology is principally an environmental consideration, and associated change is generally a matter of reactive adaptation, not creative destruction. The Cognitive school (March & Simon, 1958; Simon, 1957) has contributed concepts like "bounded rationality," "tacit knowledge," and "mental set" to an understanding of the strategist himself/herself, but an understanding of these concepts does little to advance an understanding of technology and technological change. The Political school (Pfeffer and Salancik, 1978) is concerned with resource dependencies and inter-organizational relationships, in which technological change plays a relatively unimportant role. The Cultural school (Ouchi, 1981; Peters and Waterman, 1982) is in a sense a reaction to the difficulties of managing extreme environmental dynamism, wherein technological change is perhaps an assumption but not the main focus. Members of the Environmental/Contingency school (Burns and Stalker, 1961; Hannan and Freeman, 1977; Lawrence and Lorsch, 1967; Woodward, 1965) typically view technology as being a vague environmental variable, or as a component of the organization that is practically indistinguishable from both its structure and general processes (Scott, 1993).

Other schools give considerable credit to the importance of technology, but generally view it not as a main strategic concern, but as an important tactical weapon to be used within industries. The view that strategists can actively participate in making wholesale structural changes through the management of technology is occasionally acknowledged, but is consistently underdeveloped. For example, the Planning and Positioning schools are largely concerned with the structure of existing markets and industries (Ansoff, 1965; Hofer & Schendel, 1978; Porter 1980, 1985), and perhaps best illustrate the enormous impact that Marketing and Industrial Organization have had on the field. In frameworks such as the Product Life Cycle, Portfolio Analysis, and the Five Forces Model, technology is sometimes an important focus, as implied by variables such as product differentiation and proprietary rights. However, the underlying economic assumptions are mainstream, and strategic implications are largely concerned with managing growth, maturation, and decline -- not re-creation (Hayes & Wheelright, 1988; Howard & Moore, 1988; Moore, 1988; von Hippel, 1988). In the Learning school (Burgelman, 1983; Nelson & Winter, 1982; Quinn, 1980), technological uncertainty is a driving concern but, ironically, the school has been criticized as being overly reactive to the present and hence not truly "strategic." In the Configurational school, Miles and Snow (1978) considered technology to be important in the Engineering phase of the adaptive cycle, but the crux of their framework is the Administrative phase, where crucial technology decisions have already been made and R&D's role is mostly to address cost containment. Finally, Mintzberg's (1979) configurational framework is an "all of the above as required" approach that considers technological change to no greater extent than even the sum of the other schools described.

Schumpeter's focus has not gone completely unnoticed in Strategic Management, however, and does have a tenuous place in Mintzberg's Entrepreneurial school. However, Mintzberg noted:

> Mainstream economics always held back on the role of the leader. It preferred the abstraction of the competitive market and the predictability of the skeletal leader to the vagaries of strategic vision and the innovative market niche (Mintzberg, 1990).

In other words, though the Entrepreneurial school champions the entrepreneur as opposed to the steward, its place in Strategic Management (vis-a-vis technological innovation) has remained relatively minor because of theoretical problems that have remained unresolved since Schumpeter's time:

> To undertake such new things is difficult and constitutes a distinct economic function, first, because they lie outside of the routine tasks which everybody understands and, secondly, because the environment resists in many ways ... To act with confidence beyond the range of familiar beacons and to overcome that resistance requires aptitudes that are present in only a small fraction of the population and that defines the entrepreneurial type as well as the entrepreneurial function (Schumpeter, 1976: 132).

This is not to suggest that the entire field feels that entrepreneurship is unimportant, because the opposite is generally true. Likewise, nowhere in the Strategic

Management field is it outwardly professed that technology and technological change are unimportant. The point is that pending the fuller development of a popular economic paradigm that considers the "creative destruction" phenomenon endogenously, it will be difficult for a "Technology School" to flower fully within the evolving Strategic Management field. Thus, Strategic Management researchers interested in the primacy of technology seem to face a dilemma. The options implied by the above discussion seem to be: (a) accept the most popular Economics paradigms and study technology as a secondary, tactical, or functional consideration using proxy-like measures, or (b) accept the Schumpeterian view that entrepreneurial vigor and technological expertise are foremost strategic concerns, while using undeveloped and/or possibly cross-disciplinary theory.

In pursuit of an agreeable solution, it is noteworthy that many researchers have recently "returned" to advocating a view of strategic management that emphasizes the wise development and deployment of organizational resources (assets) and competences (skills) (Barney, 1991; Peteraf, 1993; Schendel; 1994; Wernerfelt, 1984). Some advocates have stressed the importance of pursuing abnormal returns to tangible assets (Amit & Schoemaker, 1993; Conner, 1991; Ginsberg, 1994; Grant, 1991), while others have placed greater emphasis on the selection and development of human-based competences (Barney, 1992; Bessant, 1994; Lado & Wilson, 1994; Pavitt, 1994; Pisano, 1994; Prahalad & Hamel, 1990). With respect to the latter, new product development and product innovation have been identified as being important sources of competitive advantage (Barney, 1992; Hayes & Pisano, 1994; Lado & Wilson, 1994; Pisano, 1994; Stalk, Evans, & Schulman, 1992), but the consensus is not yet clear on exactly what skill accounts for innovation: "The capability that wins tomorrow is the capability to develop the capability to develop the capability that innovates faster (or better), and so on" (Collis, 1994: 148). Regardless, the point is that the Resource/Competence-based perspective is eclectic, flexible, and receptive to viewing all innovation-related issues in terms of human-based skill (Rothwell, 1994; Schendel, 1995).

Hamel and Prahalad (1994) are popular spokesmen in this regard. They have asserted that strategy should be viewed first as competition for share of mind, or opportunity share. This requires a total reconsideration of the meaning of industry and market structures. Extant understandings are so deeply embedded in the popular equilibrium models that strategic decisions are susceptible to rigidity and myopia, and the development of truly strategic thinking can become retarded. The essence of strategy, in their view, is to invest in, develop, and match an organization's "core" competence to foreseeable customer-oriented functionality, broadly defined:

> Just as it is necessary to abstract away from business units to underlying core competencies, it is necessary to abstract away from traditional product and service definitions and focus on underlying functionalities (85) ...
>
> It is the marriage of core competence and functionality thinking that points a firm toward unexplored competitive space. It is core competence and functionality thinking that allows companies to go beyond what is to what could be (88).

Because this view focuses on competences and functionalities, rather than existing industry and market structures, it invites technology under its umbrella as a prime consideration -- however, this depends on operationalizing technology not as economists have done (Sahal, 1981; Sako, 1994), but as many technologists prefer. Consider that Betz (1993) defined technology as "the knowledge of the manipulation of nature for human purposes" (374). If technology is knowledge, and if knowledge is the basis of skill, and if skill is competence, then technology is competence. Looking past materialistic conceptualizations of technology and adopting the view that technology, not unlike its cousin science, is knowledge, allows it to be considered as a candidate for core competence in Competence-based views (Pavitt, 1994; Sako, 1994, Tyler & Sttensma, 1995).

Furthermore, while technologists often prefer to conceive of technology as competence, they just as often prefer to measure it in terms of functional performance because functional measurements (a) can be objectively obtained, (b) have immediate and practical utility to managers, (c) take into account all types of innovations, (d) account for product characteristics, and (e) track the diffusion of technology (Goodman and Lawless, 1994)..

In short, Hamel and Prahalad stated that strategic thinkers should strive to match their firms' core competence with broad-based customer functionality, while technologists have very similarly stated that technology is both competence and functional performance. Despite some areas of underlying theoretical underdevelopment, this match seems direct.

Management of Technology

In order to proceed, it is necessary to emphasize what so far has only been alluded -- that many researchers in fields other than Business Administration have for years wrestled with the problem of endogenous technological change, with significant success. "Technology is ... a fundamental force for change affecting firms and their environments. There is no science yet of technological change, but there are some helpful conceptual frameworks and guidelines" (Goodman and Lawless, 1994: 178). The specific "frameworks and guidelines" referenced here are technology s-curves and technology cycles. S-curves will be reviewed first, as an understanding of this concept is essential to understanding technology cycles.

In their most elemental form, s-curves are not simply a theoretical abstraction; thousands have been developed and their explanations are simple and well-accepted (Becker & Speltz, 1983, 1986; Foster, 1982, 1986 a/b, 1988; Merino, 1990; Roussel, 1984). As originally conceived, an s-curve is an actual plot of the performance of a technology (in any vital dimension of performance) v. time (or, as originally conceived, (Research and Development (R&D) effort). It takes some time (and/or effort) to get acceptable performance out of a new, little known technology, but eventually an accumulation of knowledge, effort, investment, and number of involved people synergizes and the growth in performance accelerates. However, this growth eventually inverts as a natural limit is asymptotically approached, and the result is an s-curve. Upward movement along an s-curve depicts incremental improvement in the chosen performance parameter of a particular technology, while a transition to a different technology that has a higher theoretical performance limit is termed and graphically depicted as a "discontinuity" (Figure 2.1 depicts two individual s-curves and a discontinuity).

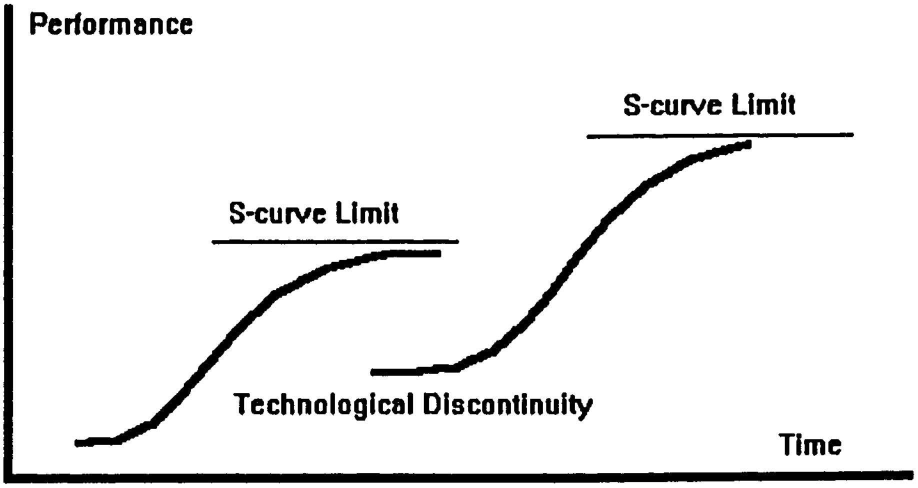

Figure 2.1 S-Curves and a Technological Discontinuity.

Many scholars, consultants and practitioners have noted the profound management implications of the many decisions related to incremental v. discontinuous technological change. Understanding the s-curve has become fundamental to understanding how technologies evolve at higher levels of analysis, and/or in complex products and product systems. The following review focuses on a general rubric often called "Technology Cycles" which, for reasons that will become clear, are particularly salient to Strategic Management decisions.

Abernathy and Utterback (1988) summarized several years of their research by articulating a framework that has become well-known and well-accepted in the Management of Technology literature. They found that in general, technology evolves in an industry in three fundamental stages. In the early Fluid Stage, competition is based on functional product performance. Product users are the prime stimuli for innovation, and thus product innovations dominate competitive dynamics. Changes in production processes are relatively easy to accommodate, and production is generally small-scale. In the second, Transitional Stage, competition is still based on product variation, but expanding internal capability stimulates major process innovations as well. At least one product design usually comes to "dominate" the market or industry, and production processes become more and more efficient and entrenched. In the latter, Specific Stage, competition is based on cost reduction and quality, which stimulates incremental improvements in both products and processes. Product differentiation becomes difficult, and process improvements promote efficiency.

Ford and Ryan (1988) expressed a framework of Technology Life Cycles that focused entirely on strategic decisions relevant to whether a firm should develop technologies internally or sell them. With a minimum of description as to the underlying dynamics, they identified the following stages of technology cycles: technology development, technology application, application launch, application growth, technology maturity, and degraded technology. Despite their lack of specifics, this framework has also become a common general reference.

In 1985, Abernathy and Clark (1988) departed from the deterministic implications of the emerging "cycle" mentality, by describing four types of innovations in terms of two dimensions that are fundamentally independent of time: (a) effect on existing markets, and (b) effect on existing firm/industry competences. Architectural Innovations are those where "new technology ... departs from established systems of production, and opens up new linkages to markets and users. They create new industries or reform old ones" (161). Market Niche Innovations "build on established technical competence, and improve its applicability in ... emerging market segments" (64). Regular Innovations involve "change that builds on established technical and production competence ... the effect of these changes is to entrench existing skills and resources" (65-66). Revolutionary Innovations render "established technical and production competences obsolete, yet [are] applied to existing markets and customers" (66). The authors found support for this framework through a qualitative study of the history of the automobile. An important implication was that firms and industries can alter their courses by pursuing specific types of innovations that suit their strategic goals, and can even "de-mature." Another important contribution was the emphasis on competences. However, though the key constructs have gained widespread acceptance, most researchers have preferred to express them, and those like them, in cyclical frameworks.

Burgelman, Kosnik, and van den Poel (1988), for example, have posited that the popular A.D. Little (1981) categorization of technologies can be roughly framed as a sequence, or evolution. In Stage I, technology is characterized as "Emerging," which means that the technology's potential to alter the existing basis of competition has not yet been demonstrated. According to Goodman and Lawless, Emerging technologies "need only be monitored through a variety of literature review and scientific meeting attendance activities" (131). In Stage II, technology is characterized as "Pacing": here, the potential for competitive advantage has been demonstrated . Investment here "needs to be done on a selective basis. The firm needs to have some hands-on experience with the core elements of such technologies in order to reduce technological uncertainties in anticipation of more effective deployment in a systematic development effort when the pacing technologies achieve key technology status" (131). In Stage III, technology is characterized as "Key," which means that it constitutes the present basis for competitive advantage. In other words, Key technologies are those which are already embedded in existing products and processes, and have a major impact on performance issues such as cost, quality, and functional performance. "Systematic investment in next-generation technology includes main products, complementary products, distribution strategies, and coordination with major customers" (130-1). In Stage IV, a "Base" technology is that which has become commodity-like and is commonly available to all competitors. "Here the focus is normally on small improvements in performance capability and continual recruitment to replace technical personnel when they move on" (130). Whether Little's categorization scheme is left as just that -- a cross-sectional categorization scheme -- or interrelated as stages in a cycle, the implication is that technological evolution and/or change is highly dynamic. Within any reasonably complex product, constituent technologies are likely to vary in some basic characteristics.

In 1986, Tushman and Anderson articulated a view of technology cycles which emphasized the discontinuity phenomenon, a view which Anderson and Tushman extended in 1990. In the earlier article, they hypothesized that there are two fundamentally different types of discontinuities: competence-enhancing and competence-destroying. Competence-enhancing discontinuities represent "orders of magnitude improvements in price/performance that build on existing know-how within a product class," while competence-destroying discontinuities are ones where "mastery of new technology fundamentally alters the set of relevant competences within a product class" (442). Importantly, they also hypothesized that competence-destroying discontinuities are most commonly made by new industry entrants, whereas enhancements are made by incumbents. In the latter article, they proposed that a discontinuity is usually followed by an era of ferment -- a period where old products are experimentally replaced in the marketplace by new ones -- resulting in a trial-and-error design competition that culminates in the emergence of a dominant design, followed by a renewed period of incremental change. Here, they maintained that incumbents usually make competence-enhancing product discontinuities and competence-destroying process discontinuities, while new entrants are usually responsible for competence-destroying product discontinuities. The authors found support for these most fundamental hypotheses through a longitudinal analysis of three industries, while making great use of personal judgment in delineating types of discontinuities. A key implication of their findings was that discontinuities are enormously affected by social dynamics implied earlier. This view has become extraordinarily popular among Strategic Management scholars interested in associated issues.

In their discussion of growth curves and product or technology life cycles, Howard and Guile (1992) reported that "technologies and industries do tend to evolve in consistent patterns that, if perceived even dimly, can help a manager chart a course in the use of technology. Management consultants, technical professionals in industry, and scholars of technical change and diffusion have done substantial work in understanding patterns by which industries and technologies evolve together ... While there is no widely accepted formal model, there seems to be agreement -- if only tacit -- that important and pervasive patterns do exist" (11).

They also proposed a three-phase technology life cycle. The Emergence phase is "characterized (1) by genuine technical novelty; or (2) by the use of a previously developed technology in a new market application" (1992: 11). In the Diffusion and Development phase a dominant design "speeds up the pace of diffusion ... price competition becomes more important ... and the pure economics of production and delivery dominate competition" (14). In the Maturity phase, the pace of technological change is slow, and technologies become endangered by the prospect of replacement.

Betz (1993) was more careful than most to note that there are different levels of technological cyclicality, and that each is relevant to a specific level of organization. Product Life Cycles mainly affect divisions, Product Line Life Cycles affect firms, Technology Life Cycles affect industries, and Kondratieff Cycles affect nations and entire economies. Since the view of Strategic Management is principally concerned with how firms compete in industrial settings (Porter, 1990), the middle two types of cycles are most salient to this study. "Although products are obsoleted by technology, cost, safety features, packaging or fashion, product lines are obsoleted by technology or safety ... substitution will begin for the applications that demand the higher performance of the new-generation product line that justifies the price premium" (Betz, 1993: 282-3).

He next noted that "the technological obsolescence of product lines can cause whole industrial sectors to die or be restructured" (283). His ensuing discussion of industrial technology life cycles was consistent with the views presented above, while making the greatest use of Abernathy and Utterback (1978) and Ford and Ryan (1981). However, he concluded by pointing out several limitations of the technology cycle concept: (a) it is oversimplified; (b) several product standards, or dominant designs, can emerge; (c) markets fragment rapidly to complicate any analysis; and (d) many products are composed of several technologies which often experience different rates of development.

In sum, the process of technological innovation and change is complex, and technology cycles capture but a general subset of all possible events. This discussion of Technology Cycles has been oriented towards several of the issues that are most important to Strategic Management researchers. Here, the general consensus is strong (Fairtlough, 1994; Freeman, 1994; Lissoni & Metcalfe, 1994; Utterback, 1994) and holds that: (a) technological innovation happens both continuously (incrementally) and discontinuously (radically); (b) because they "enhance" existing competences and build on sunk investments, existing firms (incumbents) are prone to make incremental technological innovations; (c) because they "destroy" existing competences and force massive reinvestments, new (usually small and young) entrants are prone to make radical technological innovations; (d) faced with competence-destruction, incumbents fight back; and (e) radical new technologies are most competitively disadvantaged early-on, when their performance and price characteristics are most relatively inferior to the performance and price characteristics of mature technologies, if known.

At this point, it is important to highlight that the discussion has honed its focus to product innovations in the manufactured/assembled product subsector of an overall product/service economy. This is prudent for three reasons. First the research cited above has generally indicated the leading impact that product innovations have had on the "creative destruction" phenomenon (Fairtlough, 1994; Hobday, 1994). That is, product discontinuities usually inaugurate new technology cycles, whereas process innovations generally provide the impetus towards equilibration within individual cycles. Second, though the general model is highly applicable to the non-assembled product sector, there the main constructs are less conceptually distinct (Utterback, 1994). Third, research of the main issues in the service sector is apparently much less rich (Miles, 1994). In an effort to maintain maximum clarity, therefore, all subsequent discussions will maintain a focus on assembled/manufactured products.

Technological Forecasting and Morphological Analysis

Frederick Betz has observed that

> In historical hindsight, it is easy to pick out why and even when a new technology substituted for an old technology ... the problem in forecasting and planning technology is to anticipate the change ...
>
> Initially, a substituting new technology will likely perform a given function less well than an existing technology. *Its potential for substitution lies in a natural advantage in the nature of its phenomenological base compared with the older phenomenological base* [italics added.] (1993: 392-95).

Key to improving the ability to foresee (or at least explain non-superficially) discontinuities, then, is an understanding of a product or product line in terms of the scientific/engineering phenomena being exploited and embodied into the products in question. This need begs for a forecasting tool which has a phenomenological focus. Of the techniques currently available, Morphological Analysis (MA) has exactly this focus.

The morphological method, developed in a series of obscure papers written in the 1940s by Swedish astronomer Fritz Zwicky, is now practiced by virtually every R&D organization in the U.S. (Betz, 1993). The idea initially languished. Jantsch (1967) noted "it is astonishing ... that the only technique yet developed for systematic [technological forecasting] has not received very wide attention so far" (175). By "systematic," he inferred that the morphological method was far less biased by present conditions and business pressures than methods like trend extrapolation and contextual mapping, yet far more structured and disciplined than intuitive thinking. "The practical application of the morphological method is conceivable over a wide spectrum ranging from a mere conscious or unconscious attitude to the careful construction of parameter matrices and their evaluation" (179). Jantsch quoted Zwicky's steps, which have been reproduced often in the literature:

> 1. An exact statement is made of the problem which is to be solved ...
> 2. The exact statement ... will reveal automatically the important characteristic parameters on which the solution of the problem depends ...
> 3. Each parameter "p" will be found to possess a number of "k" different independent values "pk" [sic] ...
> 4. The determination of the performance values of all the desired solutions represents the fourth major step ...
> 5. The final step involves the choice of particularly desirable special solutions and their realizations (176) ...

The sum and substance of this technique is this: complex products are principally expressed as combinations of natural phenomena. Each phenomenon is a parameter (p) which must take form via one option (k) or another. A morphological matrix (Table 2.1 provides an example) lists all required natural phenomena that must occur for the product function to happen, and then lists all known or foreseeable options which suggest how each phenomenon might be embodied. Since each option has its own *inherent* natural potential, and since some potentials are inherently more opportune than others, a morphological matrix can directly indicate which configurations are inherently higher performing than others.

In Table 2.1, for example, consider a morph of jet engines defined by a combination of all the parameter options listed in the first "Option" column. In this example, note that the first propellant parameter option is "gas" -- here is a morph of jet engines that all run on gaseous fuel, such as gaseous hydrogen. But suppose safety is a crucial performance parameter, in which case the volatility of the fuel is a key performance measure. Gaseous hydrogen (and for the sake of argument, other gaseous fuels) have inherently low and therefore relatively unsafe ignition temperatures. If no gaseous fuel has the inherent ability to meet safety requirements, regardless of any

Table 2.1. Zwicky's Morphological Matrix of Jet Engines (Jantsch, 1967).

Parameter	*Option*	*Option*	*Option*	*Option*
Energy Source	Intrinsic	Extrinsic		
Generation	Internal	External		
Augmentation (1)	Intrinsic	Extrinsic		
Augmentation (2)	Internal	External		
Jet	Positive	Negative		
Conversion	TBD	TBD	TBD	TBD
Medium	Vacuum	Air	Water	Earth
Motion	Transitory	Rotatory	Oscillatory	None
Propellant (1)	Gas	Liquid	Solid	
Propellant (2)	Self-igniting	Non-self-igniting		
Operation	Continuous	Intermittent		

possible incremental improvements to gaseous fuel technology(ies), then a discontinuity is in order. A switch in jet engine technology(ies) must be made to those which employ liquid or solid fuels, those which inherently possess higher (safer) ignition temperatures.

Ayres' (1969) contribution greatly enhanced the technique's overall usefulness; his view and terminology are important to this study and will be carefully explained. In any morphological matrix, one can identify all the configurations that exist or have already been tried. Ayres referred to this as the "occupied territory" of the matrix:

> Research and Development is primarily devoted to the systematic and detailed investigation of the known territory on the 'map,' with the objective of improving upon the performance characteristics of existing devices. On the other hand, a small but significant fraction of the total research effort goes into exploration of the adjacent 'terra incognita' ... exploration usually tends to proceed from the known part of the morphological map only into the nearby territory. In other words, it is normal and natural to vary the parameters of the initial configurations one at a time (79.)

At this point, terminology becomes important. Most important is the concept Ayres called Morphological Distance, which will be abbreviated here as MD. Ayres defined MD as "the *number* of *parameters* wherein ... two configurations differ from one another ... each time a new configuration becomes realizable [i.e., each time MD is traversed,] a technological breakthrough may be said to have been achieved ... refinements and improvements to a known configuration -- however valuable -- would not be characterized as breakthroughs ... the probability of a breakthrough in a technological area, per unit time, is a decreasing function of its morphological distance from existing art, other things being equal" (81).

Ayres used this structure to explain the s-shaped progress in any field. When a truly original product is invented, it is the first configuration and the only existing morph. As a result of entrepreneurial energy and inventive genius, different configurations (usually differing in only one parameter, or of "MD 1") appear and are tried in the marketplace. (In the earlier example, a switch from gaseous to liquid OR solid fuel is an axample of an MD 1 change, as only the first propellant parameter was switched.) Each of these tries, whether commercially successful or not, diffuses technological know-how. As such, each serves as a point of departure for subsequent new configurations (also usually of MD 1), so the growth pattern is exponential. However, since only so many configurations are possible on a given matrix or map, this growth eventually inverts, flattens out, and approaches exhaustion. Visualizing multi-parametric expansion and collapse is difficult, but the aggregate effect is an s-shaped curve of the innovation activity in a given type of product. Morphological Analysis, and especially Ayres' manner of expression, is therefore a window of opportunity for gaining an improved understanding of technology cycles.

It is interesting to note that in this view, each phenomenon/parameter is a possible locus of innovation. In Table 2.1, an MD 1 innovation might occur as the result of switching "energy source" options, or of switching "generation" options, or of switching any of the other seven phenomena/parameters. It could be said that in this particular matrix, there are nine different Phenomenological Types (PTs) of MD 1 innovations. Though Ayres did not point this out so precisely, it is inherent in his overall understanding. As will become evident in subsequent chapters, it is important to appreciate that a morphological matrix can be used to describe both the MD and the PT of any particular innovation.

Arnfield (1969) appreciated the potential that morphological analysis has not only towards mapping out technological possibilities and charting developments, but also towards optimizing relevant R&D investment decisions. His discussion emphasized morphological analysis as being the fourth step in an elaborate eight-step process. "It is a method which considers every known alternative to a problem in order to find a 'best' overall [solution] ... It is the examination of the fundamentals of a [technology] in this manner that creates favorable circumstances for radical innovations to occur, not necessarily as a direct result of rigorous analysis, but possibly sparked off by well-disciplined thought" (230).

Bright and Schoeman (1973) concurred with the growing body of advocates, but emphasized a known irony: "The main difficulty of morphological analysis lies in its great richness ... we quickly arrive at tens of thousands of solutions." As a help, the authors adopted a view virtually identical to Ayres'; they recognized the likelihood that "nearby" innovations are the ones most likely to occur. "If two different solutions differ only by one single parameter value, they are spaced by one; if they differ by two values, the distance will be two and so on ... [However,] abstract distance can aid in studying [morphological] results but only if this is not too systematized. It may be that some solutions differing by one will be as distant as solutions differing by four or five and the reverse" (448). So MD is a useful idea, but its precision as a measure is limited.

Since then morphological analysis has exploded in popularity, though its conceptual development has slowed. Taylor and Sprakes (1977) noted that "The rigorous analysis and fresh orientation on existing technologies that a morphological analysis provides is a most valuable instrument, acclaimed by R&D managers and scientists" (85). Jones and Twiss (1978) agreed while providing diverse and convincing examples, and stressed the need to prune any analysis of unfeasible configurations. There are many other mentions of both its conceptual appeal and practical utility (Garde & Patel, 1985; Fahey & Narayanan, 1986; Foray & Gruber, 1990; Majaro, 1978; Raudsepp, 1982; Sands, 1979; Wissema, 1982).

As the beginning of this section implied, Betz (1993) was particularly adamant about the unique and critical potential that morphological analysis has towards developing a technology strategy, but he stipulated:

> In technology, function and morphology are mappings, correspondences -- not mathematical derivations of one from the other ... Physical structure, morphology, can be correlated with function, but neither morphology nor function can be derived from the other ... The fundamental reason for trying to correlate morphology with functionally defined properties is the same as the reason behind invention: technology as the purposeful manipulation of nature (153).

Betz' subsequent discussion was not unlike Arnfield's, in that the morphological perspective was adopted as an essential -- indeed pivotal -- part of a larger decision-making process. Whereas Arnfield's view was more of the scientist, though, Betz' was more of the engineer.

Thus morphological analysis is a structured and correct tool for use in many modes of technological forecasting. The literature suggests many other related uses as well. It is a technique that provides structure to an understanding of technology that is more "real" than many other views, in that it deals with *ultimate* natural phenomena and potential product functionality. Its main disadvantage lies in the inherent imprecision of any map or analogy; a morphological matrix is not an empirically derived taxonomy, must be developed with care and insight, and must be understood before use. Its main advantage is its ability to map technology in-depth, in terms that are initially unobfuscated by any socioeconomic concern. A morphological matrix is a highly objective baseline from which to first assess the underlying natural limitations and opportunities for technological change, en route to assessing other complications.

Institutional Theory

The literature reviewed above consistently suggests that factors other than improved technical performance shape the assimilation of technological innovations into the marketplace. Pure "technology push" strategies -- those which rely on inventive genius without giving due attention to achieving functionality in the mind of the consumer -- are painfully vulnerable to the complexities of competitive dynamics and consumer demand. On the other hand, the literature also suggests that pure "market pull" strategies -- those which dutifully follow present consumer demand -- are themselves dangerously vulnerable to the abilities of the inventors, innovators, and entrepreneurs who do not share the general consumer myopia of what "could be" (Littler, 1994). Rather, it is usually suggested that strategists consider both approaches simultaneously (Coombs, 1994; Imperato & Harari, 1995; Leonard-Barton, 1995; Nadler et al., 1995; Rothwell, 1994.).

However, the Technology Cycles literature (Tushmna & Anderson, 1986; Utterback, 1994) also indicates that when the destruction of competences is at stake, the struggle takes on an additional dimension. That is, incumbents and new entrants fight not only for technological superiority and market acceptance, but also fight to protect and/or further develop their organizational competences. Optimizing these three considerations (superior performance, markets, and competence) poses some strategic conundrums. For example, a radical innovation (in its very early stage of development) might well be highly technologically opportune (in terms of performance potential), and highly competence-destroying (potentially), yet least demanded by the general consumer. For example, when George Westinghouse introduced his AC system, it was immediately and demonstrably superior to Edison's DC system in terms of its potential to efficiently transmit elecricity over long distances. Yet AC did not clearly dominate the electric utility industry until several decades later because of the lead, or customer base, that Edison had established (Butts & Grimm, 1994.) At points of potential technological discontinuity, then, competing for "share of mind" (Prahalad & Hamel, 1994) would seem to be a truly important but subtle thing (Salancik & Pfeffer, 1988; Van de Ven, 1988). Here Institutional Theory has some appealing explanatory potential.

Institutions are meaning systems (Berger & Luckman, 1967; Scott & Meyer, 1994). Institutions can be defined and observed in terms of existing social norms and cognitive states, and the form and level of formalization of institutions can vary enormously. Of importance here, a key assertion of Institutional Theory is that society's norms and cognitive expectations powerfully affect organizational survival and hence shape the evolution of entire populations of organizations (Meyer & Rowan, 1977).

Institutional Theory can be applied to many levels of analysis, but the most popular is the "field" level (Scott & Meyer, 1994). As defined by DiMaggio & Powell (1983), an organizational field is a recognizable/observable pattern of suppliers, consumers, regulatory agencies, and organizations that deliver products or services. As this list is strikingly similar to those found in popular models of industry structure (Marceau, 1994; Porter, 1980), the direct implication is that industry dynamics are shaped by institutional as well as economic/market forces.

In particular, it has become common to assert that an organization's chances for survival are affected by its "legitimacy" (Hannan & Freeman, 1989; Kelman &

Hamilton, 1989; McCarthy & Zald, 1977; Meyer & Rowan, 1977; Pfeffer & Salancik, 1978; Tilly, 1975; Zucker, 1983). Legitimacy is a broad but long-established construct (Parsons, 1960; Selznick, 1957; Weber, 1947) that generally refers to the degree of correctness society ascribes to an organization (Scott, 1992). The literature suggests that a degree of legitimacy is acquired through relatively uncontrollable organizational characterisitcs such as size and age (Pfeffer & Salancik, 1978; Hannan & Freeman, 1984). The literature also suggests that legitimacy might also be acquired less passively, through the imitation of various characteristics of other established and successful organizations (Haveman, 1993; Tolbert & Zucker, 1983). Finally, the literature suggests that legitimacy can be pro-actively acquired and managed through actions such as the establishment of interorganizational relationships and regulatory approvals (Baum & Oliver, 1991; Singh, House & Tucker, 1986), and even through such simple actions as making charitable contributions (Galaskiewicz & Burt, 1991; Galaskiewicz & Wasserman, 1989). In short, legitimacy is an important institutional and industrial dynamic, and has been successfully interpreted and operationalized in a variety of ways (Scott, 1995; Suchman, 1995.)

Recently, legitimacy and legitimation processes have been noted as being important factors in the probability of success of technology-based new business ventures (Aldrich & Fiol, 1994; Rao, 1995). The argument is that organization-wide legitimacy can be used as both an offensive and defensive weapon in the promotion of products and ideas which are yet to be established in the marketplace: "Skillful ... operatives seeking to legitimate their projects may draw on wider institutional logics to show that their innovation is cognitvely cogent and morally defensible" (Rao, 1995: 31). More specifically, Aldrich & Fiol (1994) argued that incumbents not only can, but often do exploit their organizational legitimacy while defending their entrenched technologies from the encroachments of potential new entrants. They borrowed the term "cognitive legitimacy" to describe in simple terms the absolute level of public knowledge that exists concerning any particular technology. Through the manipulation of cognitive legitimacy, incumbents shape the terms by which other firms are able to acquire desperately needed resources, and hence have the potential to prevent the emergence of new, potentially replacing industries. "Established industries that feel threatened by a newcomer may undermine a new venture's cognitive legitimacy through rumors and information suppression or inaccurate dissemination ... competing firms spread rumors that a product or technology is unsafe, costly, or of inferior quality" (Aldrich & Fiol, 1994: 656-7). For example, in the battle between DC and AC, Edison and his followers attacked safety concerns of AC technologies by publicly electrocuting animals with AC, by making it well-known that New York State electrocuted criminals with AC, and by making premature announcements of upcoming developments in DC technologies (Butts & Grimm, 1994.)

In short, existing firms in mature industries enjoy legitimacy, and their legitimacy is communicable to the technologies they use (Carlsson, 1994; Cooke & Marceau, 1994; Morgan, 1994; Shaw, 1994; Steinmueller, 1994). Legitimacy is resistant to change, and in fact an existing product-technology legitimacy will be actively defended by incumbents, especially when threatened (Aldrich & Fiol, 1994).

Summary

This literature review has juxtaposed four main, highly related points:

First, technology, and particularly technological change, is a critical consideration in Strategic Management. Defining technology as both organizational competence and functional performance allows it to be considered comfortably in the growing Resource/Competence-based perspective. There is a very similar and highly complementary thrust growing in the Management of Technology field.

Second, Technology Cycles frameworks have substantial explanatory ability. S-curves are their bedrock. S-curves depict technological change as incremental and discontinuous shifts in performance. Discontinuities have the potential to "enhance" or "destroy" competences. The implications for industrial evolution and Strategic Management are profound, though prediction has proved difficult.

Third, Morphological Analysis is a common tool that has the ability to both describe and forecast technological change. It focuses on phenomenological potential while delving deeply and objectively into underlying natural realities and parameters. The technique adds an important level of detail, though by analogy, to relatively abstract descriptions of incremental and discontinuous technological change.

Fourth, it is clear that technological change is not always a technically rational, linear series of choices that all opt for performance maximization. There are common situations where performance maximization, organization stability, and short-term buyer appeal are conflicting goals. Some strategic battles are fought on Institutional fields, and deserve empirical investigation.

CHAPTER 3: PROPOSITIONS

Recall that Ayres (1969) used the morphological perspective to describe two types of innovation activity: development of the "occupied territory" of a morphological matrix (or map), and exploration of the "terra incognita." He observed that most industry R&D focuses on the first type, while the second depicts "breakthroughs" that, by his definition, traverse some morphological distance.

This view is very similar to what s-curves have been purported to represent. In Ayres' definition, developing the "occupied territory," or making innovations that traverse no morphological distance (MD 0), means making incremental improvements to known configurations. This means that MD 0 innovations are those which result in upward movement along the s-curve in one (or several) of the known "pk" options. (For example, Edison's painstaking experiments that substituted light bulb filament materials were incremental, MD 0 improvements. The basic configuration of light bulbs was not changed, and underlying phenomena (such as incandescence and DC) were the same in every experiement). Making a "breakthrough" of MD 1 means enacting one specific parameter through a different technological option, or switching a "k" in a manner where the overall result is an original configuration. When a "k" is switched, then, this is also a switch from the s-curve of one technology to the s-curve of another, which is the accepted definition of a technological discontinuity. (For example, Westinghouse's choice to use the then-lesser-known AC phenomenon, rather than the much simpler and well-understood DC, was an MD 1 technological discontinuity).

At first glance, it might seem that the greater the number of technologies changed (the higher the MD), the greater the discontinuity. (For example, it seems reasonable to assert that a switch from DC to AC, AND a switch from incandescence to flourescence, is a greater discontinuity than either change, individually). While this is probably true in many cases, however, the R&D literature warns against cavalier use of the "distance" analogy. The exact number of "k" options switched defines the exact morphological distance, but there is no tight correspondence between the magnitude of MD and the magnitude of the overall discontinuity. At the present point of conceptual development, one can comfortably say only that MD 0 innovations are incremental improvements, and MD>0 innovations are inherently discontinuous. MD 0-MD>0 is a sound way to dichotomize incremental and discontinuous innovations, but assumptions of any greater measurement rigor (e.g., using MD as an ordinal measure) would be highly speculative.

Ayres' view also serves the idea that s-curves aggregate into entire cycles at higher levels of analysis. Recall that he observed that innovation activity at any point in time is a function of the number of existing different configurations in the occupied territory. MD 1 innovations occur at a slow rate early because the number of known configurations is small, but growth is exponential. This eventually inverts and flattens out because the number of permutations in any matrix is finite. In two dimensions, the cumulative growth in activity plots as an s-shaped curve. However, in order to conclude that an s-shaped pattern of cumulative activity (Ayres' view) corresponds to an s-curve of improved performance (s-curves and cycles), one must assume that inventors and innovators consciously pursue improved performance, not just random experimentation for its own sake. Another way of saying this is that invention is pursued with successful innovation -- i.e., marketplace acceptance -- as its goal. The literature supports this assumption: "The inventor, innovating entrepreneur, and the working force have, for two centuries, always been a team -- harmonious, despite frictions, if innovation was to succeed ... the composition of the stream of invention and innovation is substantially determined by profit incentives." (Rostow, 1993: 457-463). Thus exploration of the terra incognita has the general effect of improving performance, as well as the specific effect of simply trying the untried. That being the case, one would assume that as the exploration of a matrix neared exhaustion (Lissoni & Metcalfe, 1994), the concomitant decrease in the growth rate of performance would inspire the transition of innovation effort to an entirely new map -- a discontinuity of even higher order than "mere" MD changes within a matrix. This is one useful explanation of why the relatively simple s-curve of an individual technology is the foundation of much more complex patterns, like cycles.

In sum, s-curves have been used to explain the fundamentals of technological progress at many, different levels of analysis (e.g., better organophosphate insecticides (Becker & Speltz, 1983) at the "low" end, to economic long waves at the "high" end (Betz, 1987)), and (b) at any level of analysis, s-curve dynamics can be explained in multidimensional detail using the morphological perspective (e.g., morphological analysis has been used to improve understandings of technological progress from the refinement of clay bricks (Taylor & Sparkes, 1977) to the overall socioeconomic structure of transportation systems (Ayres, 1969). The morphological view can be applied at any level of analysis -- the only concern is that the problem be precisely stated and maintained.

It is also important that Ayres' description was not purely technical. He noted that MD>0 innovations are rare not only because they are technically difficult; they are rare because they incur risk and investment in new and unfamiliar technologies. In the "technology is competence" view, this is the same as saying that any MD>0 innovation requires renewed learning. More specifically, it requires relearning at the most fundamental level, as far as technologists are concerned -- at the level of basic phenomenological expertise. Therefore, a morphological matrix is not only a map of phenomena and options. It is also a map of competences. Innovations of MD 0 build on and enhance existing competences. Innovations of MD>0 are competence-destroying at least to some extent because the choice of a different "k" simultaneously and necessarily chooses new/different phenomenological expertise. The MD 0-MD>0 dichotomy is analogous to both the competence enhancement-v.-destruction dichotomy and the incremental-v.-discontinuity dichotomy.

However, this view differs from that found in the literature, which identified some discontinuities as competence-enhancing (i.e., not all discontinuities were found to be competence-destroying) (Anderson & Tushman, 1990; Tushman & Anderson, 1986; Utterback, 1994). The explanation lies in whether one is considering discontinuities *ex ante* or *ex post*. Morphological Analysis is principally a forecasting technique and the premise of examination is *ex ante*. As described above, in this view all discontinuities have some degree of competence-destroying potential, whereas all incremental improvements are competence-enhancing. In contrast, discontinuities described in the literature as being either competence-enhancing or destroying were observed *ex post*, along with the unmistakable impression that socioeconomic factors, not only technical/technological rationality, shaped their development. Since the present intent of using Morphological Analysis is to provide an objective map of phenomenological reality, for forecasting purposes, at least initially unobfuscated by socioeconomic complications, it is impossible in the abstract to differentiate which MD>0 innovations will enhance or destroy existing industry competences. It is wise to postpone this assessment until after an objective morphological analysis has been made.

However, as introduced briefly in the previous chapter, MD is not the only useful dimension suggested by the morphological view. Other fundamental, qualitative differences among the technologies in any matrix suggest that phenomenological parameters are themselves categorical predictors of overall patterns of innovation activity. An explanation follows.

In the A.D. Little (1981) view the present state of a technology's maturity defines it as being base, pacing, key, or emerging. This rough but popular categorization scheme classifies a technology as to its ability to to alter the present basis of competition, with strong allusions to its state of maturity (Burgelman, Kosnik, & van den Poel, 1988; Goodman & Lawless, 1994). Unless these qualities are randomly distributed in a morphological matrix, it is unlikely that patterns of innovation will be invariant across all phenomenological parameters. For example, assume that the "k" option in a particular parameter in an industry's dominant design is near the top of its s-curve (and is "base,") while several of the other options in that parameter are technologies that are on the steep parts of their s-curves (i.e., they are "key" or "pacing.") There should be a large amount of MD>0 innovation activity here. At the other extreme, assume that there is still much room for improvement in the dominant design (i.e., the same pk is "key") while all other options of that parameter are either "emerging" or "base." Most innovation activity here would likely be of MD 0.

Overall, improvements and changes in some phenomena are very likely to be more opportune than improvements and changes in others, based only on s-curve characteristics that exist at any point in time. Some Phenomenological Types (PT) of innovation are more likely to occur than others. As will be more fully explained below, PT will be used to identify and classify an MD>0 innovation according to which parameter is switched. In the earlier jet engine example, the propellant parameter of concern could arbitrarily be designated parameter number nine, simply because it appears ninth from the top in the morphological matrix. A switch from gaseous to liquid or solid fuel could be called an MD 1, PT 9 discontinuity. When this happens, a small number of phenomena will be observed as natural windows of strategic opportunity. However, as explained in the ensuing discussion, it is also unlikely that associated patterns of strategic activity will be invariant among the different types of players.

Propositions and Hypotheses

In short, the manifold conceptual appeal of morphological analysis is augmented by its ability to dimensionalize innovations in terms of "Morphological Distance" and "Phenomenological Type." This compels an empirical examination of these two dimensions. It is appropriate to start by examining one of the strongest contentions of the relevant literature (Abernathy & Clark, 1985; Anderson & Tushman, 1990; Betz, 1993; Fairtlough, 1994; Granstrand & Sjolander, 1994; Tushman & Anderson, 1986; Utterback, 1994):

P1: Industry incumbents make competence-enhancing innovations; industry non-incumbents make competence-destroying innovations.

Again, it has been suggested that MD 0 innovations are competence-enhancing, and that MD>0 innovations are competence destroying at least in their potential. From this point forward the unwieldy "in their potential" qualification will be dropped, and all MD>0 innovations will be considered competence-destroying based purely on the technical logic outlined earlier.

Also, thus far the baseline of comparison has been described as the "occupied territory" (Ayres, 1969), operationalized as the collection of known/existing configurations. The Management of Technology literature strongly asserts that in the latter stages of technology life cycles, a very small number of dominant designs (typically one) is usually self-evident (Abernathy & Utterback, 1988; Anderson & Tushman, 1990; Betz, 1993; Goodman & Lawless, 1994; Utterback, 1994). As this is the condition of keenest interest here, MD 0 will be operationalized as the configuration defined by the dominant design. In a sense, this opens up the "once occupied but since abandoned" territory to renewed exploration, but this does not inject any new problems because the enhancement and/or destruction of *present* competences is the only concern. For example, AC is certainly part of the existing dominant design in the electric utility industry. It replaced DC (which is inherently safer) because it could be transmitted over long distances, which allowed industry concentration. Yet recent advancements in technologies such as superconductivity, coupled with some deconcentration of the industry as individual homeowners and small communities install (solar or wind-powered) systems independent of larger power grids, suggests that Edison's DC fundamantals be reconsidered.

Therefore, one can hypothesize that the Morphological Distance (MD 0 or MD>0) of an innovation from the dominant design is related to the incumbency of the innovating firm:

H1a: Industry incumbents make MD 0 innovations; industry non-incumbents make MD>0 innovations.

Again, however, some situations will encourage or practically mandate some incumbent adventurousness (Abernathy & Clark, 1988; Burgelman, Kosnick, & van den Poel, 1988; Goodman & Lawless, 1994; Little, 1981). One such scenario was described earlier -- where a dominant design is mature (at least in part) and alternative options seem to be presently opportune. Such a condition invites intense incumbent activity. While some non-incumbents might also identify such situations as vulnerabilities and move to exploit them, however, it is not necessarily true that their collective reactions will mirror the relatively focused incumbent pattern.

In fact, it is reasonable to assert that the while the aggregate pattern of incumbent innovation activity will be phenomenologically focused, the non-incumbent pattern is likely to be relatively diverse. In the first place, non-incumbents might feel it unwise to compete in an area where incumbents seem strong and determined to succeed -- for that matter, they are not obliged to compete at all (Coombs, 1994; Grandstrand & Sjolander, 1994). Thus a mature industry tuned to a dominant design might be focused on a single "core" phenomenon/competence, while the core competences of all imaginable new entrants are likely to be much more diverse. Second, it is conceivable that a group of non-incumbents, all from one specific industry with its own different core phenomenological competence, might move collectively and establish itself as a new group in the original industry in question (Hamel & Prahalad, 1994). Furthermore, new entrants are not necessarily new/young firms -- they might have "deep pockets" that can afford to subsidize long-term commitments to promising, but as yet emerging, technologies (Pavitt, 1994; Rothwell, 1994).

In short, there are several reasons to suspect that non-incumbent-initiated discontinuities will form a pattern that is different than that of incumbent-initiated discontinuities. Many combinations of factors can be envisioned, but in general, the distribution of (incumbent v. non-incumbent) innovation activity across phenomenological types of innovations is not likely to be random. This leads to the assertion that PT is also a categorical predictor of incumbency. However, in the abstract this reasoning can only be applied to MD 1 innovations; categorizing an MD>1 innovation as any specific PT is very unwieldy. In other words, groupings are difficult to assess: an MD 2 innovation that changed PT 1 and 2 should not automatically be assumed to be the same as an MD 2 innovation that changed PT 1 and 3, and so on. In the earlier jet engine example, an MD 2 discontinuity that changed PT1 (energy source) and PT 2 (generation) is not the same as an MD 2 discontinuity that chaged PT 1 and PT 3 (augmentation). However, once a matrix is explicated so clearly, it might be appropriate to group all MD2/PT1/PT2 discontinuities together as one category, and to group all MD2/PT1/PT3 discontinuities together as another category. Therefore, at the simplest level and pending a more specific analysis,

H1b: For MD 1 innovations, incumbents make different phenomenological types (PTs) of discontinuities than non-incumbents.

Next, the literature makes it clear that existing industry players should be expected to take strategic actions that reflect the implications of competence enhancement and destruction (Abernathy & Clark, 1985; Anderson & Tushman, 1990; Tushman & Anderson, 1986; Utterback, 1994). More specifically, incumbents should be expected to act both defensively and offensively when protecting their investments. In the morphological view, this means that they will defend MD 0 innovations and attack the MD>0 innovations made by others. Their own explorations of MD>0, of course, they will also defend, but these efforts should only occur selectively at certain technologies (PTs).

It is reasonable to assume that incumbents often have the ability to appreciate the fundamental mechanics of technology cycles, despite the fact that their apparent strategies usually indicate reluctance to make radical changes (Foster, 1986; Utterback, 1994). In certain scenarios, they should recognize that the remaining potential to improve the performance of the dominant design -- or at least some of its constituent technologies -- is rather limited. At least they should recognize decelerating performance growth. At the same time, they should be aware that the present performance of the dominant design is impressively better than the present performance of possible MD>0 substitutes. An astute incumbent should also realize that the phenomenological potential of some substitutes is greater than the upper limits of the dominant design, and that their slow performance growth is quite possibly a temporary condition.

Focusing on only these essentials, incumbents determined to defend themselves (which is more likely than voluntary self-destruction, except for important and modest MD 1 exceptions) should be expected to take several rather obvious courses of action (whether or not they are wise). One, they should defend the short-term performance advantages of innovations in the dominant design vis-a-vis the unproven and theoretical future performance advantages of competence-destroying innovations. Two, they should attack the short-term performance disadvantages of these alternatives, while downplaying the probable long-term performance disadvantages of innovations in the dominant design.

When doing so, incumbents should be expected to use any available resources, especially those where they hold an advantage. As suggested in the literature, one vital advantage incumbents hold vis-a-vis competence-destroying new entrants is the legitimacy of their technologies (Carlsson, 1994; Cooke & Morgan, 1994; Freeman, 1994; Marceau, 1994; Shaw, 1994; Steinmueller, 1994). Conversely, one would assume that radically different technologies would suffer a lack of legitimacy and that this lack is a serious vulnerability. Indeed, Suchman (1995) suggested that new entrants are well-advised to heed this disadvantage and take much effort to overcome it. On the whole, incumbents should be expected to use the legitimacy (Ashforth & Gibbs, 1990; Haveman, 1993; Tolbert & Zucker, 1983) of existing technologies as both an offensive and defensive weapon, and new entrants should be expected to try to establish legitimacy. Early on, the legitimacy advantage clearly belongs to incumbents.

Aldrich & Fiol (1994) made a similar argument about incumbents and new ventures, even asserting that incumbents commonly embark on smear campaigns. In the same argument, they identified the news media as a good up-to-date source of information. On the other hand, they noted that media depictions are sometimes inaccurate or distorted because reporters are not always fully familiar with all important and/or pertinent details. One would assume that this is no less true concerning advanced technological matters where the average journalist probably lacks the time and other resources it takes to discern, understand and represent with perfect objectivity issues that are controversial, ambiguous, and difficult to translate for average media consumers.

This suggests that it is possible for incumbents to actively influence the reporting of developments in technology; that the public media is both part of, and affected by, a complex milieu of institutional activity. More to the point, it is likely that the media does not merely observe technological change and associated business strategies; they likely participate (wittingly or unwittingly) in the strategic responses that incumbents make to competence-destroying threats. In subtle contrast to Aldrich & Fiol's implications, it is more accurate to say that when observing media activity one is observing (first-hand) the actual cognitive legitimation of industrial activity, rather than just observing (second-hand) the activities per se.

Stated differently, it is not automatically safe to assume that absolute amounts of media activity accurately reflect the absolute amounts of innovation activity actually occurring in various industry sectors, even in the most general sense. The true aggregate amount of non-incumbent activity (e.g., "basement" entrepreneurism, and/or other low profile or "proprietary" efforts, and/or work done outside the U.S.) might actually be greater than the true aggregate amount of incumbent activity; yet due to the momentum of a technology's existing cognitive legitimacy, the absolute amount of media coverage might be greater concerning the latter. It is not plain that an overall level of media coverage always represents an actual level of activity. All that can be confidently asserted is that what is communicated through the media is a pattern of cognitive legitimation.

In sum, mature technologies are cognitively legitimate (Haveman, 1993; Tolbert & Zucker, 1983) and this legitimacy is an initial competitive advantage (Carlsson, 1994, Freeman, 1994; Marceau, 1994) in the battle for mind share (Hamel & Prahalad, 1994; Salancik & Pfeffer, 1988, van de Ven, 1988) waged in information campaigns (Aldrich & Fiol, 1994, Rao, 1995). The dominant design should enjoy the highest degree of cognitive legitimacy (Anderson & Tushman, 1990; Tushman & Anderson, 1986; Utterback, 1994), so if information campaigns are successful, competence-enhancing innovations should (1) attract relatively large amounts of media attention and (2) be ascribed the existing legitimacy of the dominant technology(ies). Conversely, if information campaigns are successful, competence-destroying innovations should (1) attract lesser amounts of attention, and (2) be easily denigrated. Where legitimation effects are particularly powerful -- i.e., where incumbent attempts to manipulate mind share are successful -- this should be true even in instances where MD 0 innovations are relatively trivial and unrepresentative of any real change, and where MD>0 innovations are important, potentially revolutionary, and newsworthy.

As such, where proactive legitimation (Baum & Oliver, 1991; Galaskiewicz & Burt, 1991; Galaskiewicz & Wasserman, 1989; Singh, House & Tucker, 1986) is successfully used as part of the defense of existing competences, the advantages of incumbents' innovations will be presented more frequently in the public media than non-incumbents' innovations (Aldrich & Fiol, 1994). At the industry level,

P2: The short-term performance advantages of competence-enhancing innovations are presented in public media channels more frequently than the long-term performance advantages of competence-destroying innovations.

Parallelling the logic presented in the first set of hypotheses,

H2a: Public media channels present the short-term performance superiority of MD 0 innovations more frequently than the long-term performance superiority of MD>0 innovations.

H2b: For MD 1 innovations, public media channels present the long-term performance superiority of some Phenomenological Types (PTs) of innovations more frequently than others.

The other half of the argument is equally important:

P3: The long-term performance disadvantages of competence-enhancing innovations are presented in public media channels less frequently than the short-term performance disadvantages of competence-destroying innovations.

H3a: Public media channels present the long-term performance inferiority of MD 0 innovations less frequently than the short-term performance inferiority of MD>0 innovations.

H3b: For MD 1 innovations, public media channels present the short-term performance inferiority of some Phenomenological Types (PTs) of innovations less frequently than others.

Next, while there is little doubt that the substitution of one technology for another primarily depends on relative performance (Foster, 1986), the literature also makes clear that the relationship among performance and price is critical (Utterback, 1994). That is, though performance is the driving parameter, the mass-market substitutability of one technology for another becomes more and more certain as price/performance ratios become more and more similar (Porter, 1980).

Here, the price advantages and disadvantages of competence enhancing and destroying innovations follow a very similar pattern as outlined concerning performance alone. In the short run, incumbent (dominant design) technologies enjoy "base technology" characteristics that are beneficent to cost: strong scale and learning effects, amortization over large sales volumes, commodity pricing of raw materials, etc. (Burgelman, Koznick, & van den Poel, 1988; Goodman & Lawless, 1994; Little, 1981) Cost of production is low and this enables a strong price/performance barrier. However, as with performance, the potential to make substantial further improvements in these factors is limited. Conversely, non-incumbent (competence-destroying) technologies are much more likely to be characteristically "emerging," and comparatively expensive because of the initial absence of significant scale, learning, volume, and commodity pricing conditions. However, the potential for improvement is very large, and there is no *a priori* theoretical reason to expect that relative future prices will not achieve rough parity, if not unequivocal superiority.

In short, incumbents enjoy at least short-term price/performance advantages because of cost drivers (Utterback, 1994). However, over time this advantage will almost certainly deteriorate, but only to the extent that newcomers are successful (Foster, 1986). Therefore in order to defend their competences in a manner consistent with the propositions discussed above, incumbents should be expected to defend the price advantages of innovations in the dominant design, and attack the price disadvantages of competence-destroying innovations. Here, the public media is no less opportune (Aldrich & Fiol, 1994; Rao, 1995) as a means of influencing cognitive legitimacy (Scott & Meyer, 1994). Again, at the industry level,

P4: The short-term price advantages of competence-enhancing innovations are presented in public media channels more frequently than the long-term price advantages of competence-destroying innovations.

H4a: Public media channels present the short-term price superiority of MD 0 innovations more frequently than the long-term price superiority of MD>0 innovations.

H4b: For MD 1 innovations, public media channels present the long-term price superiority of some Phenomenological Types (PTs) of innovations more frequently than others.

and

P5: The long-term price disadvantages of competence-enhancing innovations are presented in public media channels less frequently than the short-term price disadvantages of competence-destroying innovations.

H5a: Public media channels present the long-term price inferiority of MD 0 innovations less frequently than the short-term price inferiority of MD>0 innovations.

H5b: For MD 1 innovations, public media channels present the short-term price inferiority of some Phenomenological Types (PTs) of innovations less frequently than others.

Summary

The argument is summarized as follows. *Ex ante*, developing the known territory of a morphological map, or making MD 0 innovations (Ayres, 1969; Bright &

Scoeman, 1973), is to make incremental improvements (Betz, 1993; Foster, 1986) to known technologies and as such is inherently competence enhancing (Goodman & Lawless, 1994, Tushman & Anderson, 1986). Exploring the terra incognita, or making MD>0 innovations, is to make discontinuous changes in technologies and as such is potentially competence-destroying. Since competence enhancement and competence destruction have been found to be very strongly related to a firm's incumbency (Anderson & Tushman, 1990; Fairtlough, 1994; Utterback, 1994), the MD of an innovation should be related to the incumbency of the innovating firm (H1a). .

However, this relationship should not be perfect. Under opportune, phenomenologically-definable conditions, some incumbents will attempt MD>0 innovations (Abernathy & Clark, 1988; Burgelman, Kosnik, & van den Poel, 1988; Goodman & Lawless, 1994). Non-incumbents, however, will not respond identically to the incumbents. Incumbents will attempt Phenomenological Types of innovations that are different from the Phenomenological Types of non-incumbent innovations. PT is related to the incumbency of the innovating firm (H1b).

Incumbents will defend their competences from destruction (and/or their preferred modes of discontinuous innovation) by engaging in proactive information campaigns (Aldrich & Fiol, 1994; Haveman, 1993; Rao, 1995; Tolbert & Zucker, 1983). They will exploit the competitive advantage they hold in the legitimacy of their technologies (Carlsson, 1994; Freeman, 1994; Marceau, 1994) by influencing media representations of the inherent phenomenological advantages and disadvantages of their own innovations and those of non-incumbents (H2a through H5b).

As each Morphological Analysis will be idiosyncratic to the specific research scenario, the above argument is general. However, if the overall approach is valid, its focus on unobfuscated natural phenomena portends important generalizability.

CHAPTER 4: RESEARCH DESIGN

The hypotheses developed in the previous chapter will be tested as follows: first, a morphological analysis will be conducted of the crucial technological bottleneck in the electric vehicle industry, culminating in the development of a morphological matrix (Appendix 1, Table A.1). This matrix will serve as the basis for measuring the Morphological Distance and Phenomenological Types of the product technology innovations that will be identified through a structured content analysis of public media items (Bailey, 1982) collected continuously over a period of two years. The structured content analysis will also collect data that are designed to assess the incumbency of manufacturers and the legitimacy of the different kinds of innovations. Each hypothesis will be tested through a chi-squared analysis of a contingency table.

Sample and Data

Raw data for the structured content analysis portion of this study will consist of about 2000 public media items collected over a period of two years, April 1993 to March 1995. These items were collected through a formal in-house effort performed at the General Motors Electric Vehicles Division. General Motors is a key player in the automobile industry past, present and future. As electric vehicle developments have been unfolding, it has been in the best interest of General Motors to keep its executives well-informed. One way it has done this is by operating its own "clipping service" tasked to professionally and systematically review domestic and international newspapers, magazines, journals, press releases, syndicated newswire releases, government reports, trade association and activist group publications, and transcripts of television and radio telecasts/broadcasts for any article, editorial, advertisement, or in a word, item, containing information pertinent to the electric vehicle industry. This effort has published and distributed for internal executive use a semi-monthly report which presents these items to the reader in their raw form. Though the clipping service has done a minor amount of organizing these items into logical groupings, there is no apparent editing or defacing of any of them. Since each item is public knowledge, each will be considered in this study.

It is important to note a few characteristics of the time period assessed. First, as of this writing April 1993-March 1995 is very recent, and encompasses the time period of available data. This allows a "real-time" study of the dynamics of the electric vehicle industry that is blind to the shape and structure that the industry will have in the future, if indeed the industry successfully develops. At the moment it is very difficult to predict what the important "breakthrough" in technology will be, if it occurs.

Second, it is important to note that while the period under consideration was one of technological excitement, it was otherwise reasonably stable. The California statutes "shocked" the automobile industry, but this happened in 1990. Since then, political resolve on this issue at the state level has wavered little in the face of turmoil at the national level. First, the U.S. Presidency changed hands in 1992. The Clinton administration inaugurated a federally-funded "supercar" project designed to restore U.S. competitiveness through the development of, among other technologies, very efficient engines. However, even a super-efficient automobile can never be (for phenomenological reasons) a zero-emissions vehicle, and despite the Administration's leadership the EV movement has only spread from California to other states. Second, the political power held in the U.S. Senate and House of Representatives changed parties during the period of this study (November, 1994). Despite some changes in both elected and non-elected government officials, however, there has been no "sea change" in the Federal Government's position regarding states' rights to impose zero-emissions laws on the automobile industry. Finally, since the 1998 deadline is about as far into the future as the imposition of the California zero-emissions mandate is in the past, this study is positioned to observe the temporal center. In short, at present there is no political movement afoot or deadline pending that would seriously distort the context of the time period April 93-March 95. Though the market for electric vehicles was "mandated" by legislative action, this context has been stable and has allowed businesses to pursue industry development in reasonably normal, or at least consistent, terms.

Measures

The measures that will be used in this study will be discussed in the order that the associated variables appeared in the hypotheses developed in the previous chapter.

Competence enhancement and competence destruction: These variables will be measured through the use of two morphologically-defined dimensions: Morphological Distance (MD) and Phenomenological Type (PT). The theoretical rationale for each dimension was explained as the propositions were developed. The more specific explanations that follow are based on the morphological analysis developed in this chapter, and corroborated by experts in appropriate fields (see Appendix 1).

Morphological Distance will be expressed as a dichotomy: MD 0 or MD>0. As explained, when considering a mature industry it is reasonable to operationalize MD 0 as the prevailing dominant design. In the case of electrochemical cells intended for use in electric vehicles, there is no question that the lead-acid secondary battery is the dominant design (Brant, 1994; Hackleman et. al., 1994). Using the morphological matrix and an understanding of the dominant design from technical data, the MD 0 morph is

Parameter	Option
Redox	Lead-Acid
Commonality	Combined
Temperature	No Control
Regeneration	Feasible/present

Any device that is different in one or more of the above options will be considered MD>0.

Again, in this study only MD 1 innovations will be categorized by Phenomenological Type. The following scheme will be used:

Parameter Option Changed	PT
Redox	1
Commonality	2
Temperature	3
Regeneration	4

Ordinarily, assessing both the MD and PT of an innovation from a morphological matrix would require familiarity with the product. Fortunately, battery and fuel cell nomenclatures are very expressive and the matrix developed for this particular study is quite transparent. For example, most battery nomenclatures automatically identify the option chosen for PT 1: lead-acid, nickel-cadmium, and so forth. On the other hand, in the raw data batteries will probably be expressed in terms that vary slightly: Lead-Acid, Pb-Acid, and $PbSO_4$ are slightly different ways of expressing the same PT 1 option, for example, as are Nickel-Cadmium and NiCad. The morphological matrix will be used to determine how these slight variations in terminology will be collapsed into phenomenologically identical morphs. Ambiguous or unidentifiable cases (where MD can not be assessed per the described dichotomy, and/or PT can not be identified) will be discarded. As it is impossible to predict with certainty all possible terms, a full elaboration of these judgements can not be offered until data has been coded.

Table 4.1 presents a composite of the many types of electrochemical devices that are either under development or are being considered for development for electric vehicles (Brant, 1994; "Electric vehicles and batteries," 1994; "Energizing ...," 1993; "Fuel cell update," 1994; Hackleman, 1992; Hackleman, 1993; Henrickson, et. al. 1994;

Table 4.1. Electrochemical Devices and Morphological Measures.

Nomenclature	MD	PT
Batteries		
Aluminum Air	3	-
Lead-Acid	0	0
Lithium Carbon	2	-
Lithium Iron (Di)Sulfide	2	-
Lithium Polymer	2	-
Lithium Vanadium	2	-
Nickel-Cadmium	1	1
Nickel-Iron	1	1
Nickel Hydrogen	2	-
Nickel-Metal-Hydride	1	1
Nickel-Zinc	1	1
Sealed Bi-Polar Lead Acid	1	2
Sodium Metal Chloride	2	-
Sodium-Sulfur	2	-
Zinc Air	2	-
Zinc Bromine(ide)	1	1
Zinc Chloride	1	1
Fuel Cells		
Alkaline Potassium Hydroxide	3	-
Molten Carbonates	3	-
Phosphoric Acid	3	-
Solid Oxides	4	-
Solid Polymer (non-regenerative)	3	1
Solid Polymer (regenerative)	1	1

"The fuel cell solution," 1994; Winter & Brandes, 1994). The great amount of overlap among these sources suggests that the table is virtually exhaustive. Based on available technical descriptions, the MD and PT of each device has been evaluated and is also presented. This table will serve as a "boilerplate" for coding the MD and PT of the innovations identified in the media items. Any additional innovation that is discovered while coding the data will be added to the table with an appropriate technical assessment of its MD and PT.

Industry Incumbency: Measuring industry incumbency is not a straightforward task because neither "industry" nor "incumbency" have clear definitions and unambiguous boundaries, particularly when the diffusion of technology(ies) becomes an important issue (Bettis & Hitt, 1995). In an attempt to maintain consistency with the theoretical point of view presented in earlier chapters, the literature was canvassed for a precedent. There, measures of both industry and incumbency were usually made arbitrarily and/or qualitatively. Often, industry was associated with Standard Industrial Classification (SIC) Codes, then assuaged by judgement; incumbency was often tailored to be consistent with the intent of a study's hypotheses.

As such, for the present study the Standard industrial classification manual, 1987 (the most recent edition) was consulted, and the following logic emerged. SIC 3711 is "Motor vehicles and passenger car bodies," and specifically includes both internal combustion engine and electric passenger vehicles intended for highway use. SIC 3714 is "Motor vehicle parts and accessories." No electric power source is specifically listed under this heading, but there is a verbal reference to SIC 3691, "Storage batteries." (In contrast, there is no reference to SIC 3692, "Primary Batteries.") SIC 3691 is described as "Establishments primarily engaged in manufacturing storage batteries," under which is listed "Alkaline cell storage batteries; Batteries, rechargeable; Lead -Acid batteries (storage batteries); Nickel Cadmium batteries; Storage batteries" (1987; 232).

Thus according to prevailing industry logic, all electric power sources for automobiles come from the storage battery industry; on the other hand, it is not true that the automobile industry is the only customer of the storage battery industry. In fact, some storage battery manufacturers are probably more closely associated with other industries which produce products like laptop computers, camcorders, and other portable electric accessories. Thus using SIC 3691 to delimit the boundaries of the "industry" relevant to the present research question and scenario seems to invite a degree of confounding. However, this concern only serves to point out that an *ex post* evaluation of industry structure will frequently be different than that developed from a morphological perspective -- there is no phenomenological reason to eliminate non-lead-acid storage batteries from consideration. Any battery capable of deep discharge and regeneration (a storage battery) is phenomenologically consistent with the general performance demands of an electric vehicle. Other than lead-acid, they are not frequently used in automobiles only because their present performance is inferior. SIC 3691 adequately defines the "industry" of present interest.

In an effort to make the most objective assessment of which firms are incumbent to this industry, several popular business directories were consulted, compared, and contrasted (ABI Inform, Compact Disclosure, Directory of Corporate Affiliations, Dun & Bradstreet's Million Dollar Directory, Moody's Industrial Manual, Standard & Poor's, and Ward's Business Directory). Of these, only Ward's Business Directory (1994) has no criteria for inclusion (such as public ownership, or minimum number of employees, sales, net worth, or fee) that would unnecessarily eliminate viable candidates from consideration, other than the exclusion of non-U.S. businesses. (But considering the political and geographic context of the present scenario, eliminating non-U.S. firms is not unreasonable; in fact, it could be argued as being preferable). Furthermore, Ward's data collection approach is consistent with an academic researcher's preferences -- the Directory lists 142,000 public and private companies "culled from more than 4,000 business publications, ... annual reports, trade associations, government documents, and telephone interviews" (viii).

Table 4.2 presents the names of those firms included in Ward's directory whose primary SIC is 3691, in alphabetical order. Though the storage battery industry is to be highly concentrated (the top two firms commanded almost 37% of industry sales; the

Table 4.2 Industry Incumbents.

Acme Battery Mfg. Co.
Alexander Battery Corp.
AMP King Battery Inc.
Aristo-Craft
Battery Engineering, Inc.
Battery Technology, Inc.
Charter Power Systems
Continental Mfg Corp.
Crown Battery Mfg. Corp.
Daniel Battery Mfg. Co.
Douglas Battery Mfg. Co.
Duracell
Eagle-Picher Industries Inc.
East Penn Mfg Co.
Edwards Battery Inc.
Electruk Battery Co.
Encore Group, Ltd.
Enpak, Inc.
Eveready
Exide Corp.
Gates Energy Inc.
GNB Battery Inc.
Great Batch
Green Mfg Co.
Howard Eldon, Ltd.
K.W. Battery Co.
Linwood Mfg
Marathon Technologies
Mixon, Inc.
New Castle Mfg. Inc.
Norton Battery Co.
Ovonic Battery Co., Inc.
Palos Verdes Building Co.
Power battery Co.
Power Conversion, Inc.
Power-Sonic Corp.
Quick Cable Inc.
Ramcar battery, Inc.
Rayovac
Sanyo Energy USA Corp.
Standard Industries Inc.
TSI Power Inc.
VDO-PAK Inc.
Voltmaster, Inc.
Yuasa

top eight commanded 94%; the bottom 35 firms combined commanded about 6%), it is important at the outset of this study to not consider concentration (and by association, firm size) as an important consideration as to whether firms will resist competence-destruction. Aside from the simple intuition that suggests that the destruction of a firm's technologies/competences will be resisted "no matter what," the following discussion elaborates why.

It is known that industry concentration is related to high capital/output ratios, though the reason(s) for the relationship is(are) not well-understood (Tirole, 1990). Regardless, the relationship suggests that in concentrated industries, the Minimum Efficient Scale (MES) and the percentage of assets that are highly specialized (asset specificity) are also both high (Carlton & Perloff, 1990). In simpler terms, it is likely that the storage battery industry is capital-intensive and that the flexibility of the capital is severely limited, in terms of possible product variety. Intuitively, this aspect of the industry's overall "structure" does suggest that firms will resist the kind of changes that would be brought by a true technological discontinuity -- the massive costs of industry-wide recapitalization would be prohibitive.

But one might be tempted to infer within-industry variance in innovation among SIC 3691 firms, since there are such large differences in the sizes of the firms (assuming that sales volume is at least a partial/proxy measure of firm size). However, the enormous amount of research done on the relationship(s) between innovation and firm size has failed to generate unequivocal conclusions (Angelmar, 1985; Hambrick, MacMillan & Barabrosa, 1983; Lunn & Morton, 1986; Rosenberg, 1976; Tassey, 1983). It is NOT clear that large firms are non-innovative and that small firms are innovative (Sharp, 1994); what IS more clear is that differences in firm size confer different types of advantages to innovation (Rothwell & Dodgson, 1994). In general, while large firms have material advantages, small firms have behavioral advantages (Rothwell & Dodgson, 1994.) (Audretsch (1995), for example, found that small firms survive in high-MES industries by making more efficient and dynamic use of labor than large firms, as a partial offset to inefficiencies of low scale). On the whole, firms within an industry complement each other, acting as specialized units of one huge rent-generating mechanism integrated by market rather than administrative mechanisms (Hobday, 1994). Firms of different sizes engage in a very wide variety of collaborative relationships and over time (and especially in mature industries), pursue similar technological trajectories.

Stated differently, the greatest firm-size differences in innovation have been found to exist between sectors (industries), not within them. Rothwell & Dodgson (1994), for example, found significant differences among twenty-four industries in the firm-size differential (the arithmetic difference of the averages between large and small firms) in their rates of innovation (measured as the number of innovations per thousand employees). In the storage battery industry, the differential (.96) was fourth closest to zero (the range across all industries in the study was -7.90 to 8.46). In the storage battery industry, therefore, there is no conclusive theoretical reason or empirical evidence to support the speculation that firm size is related to innovation in terms that are meaningful to the *present* research question. For the purposes of this study, firm size does not differentiate incumbency, and all firms listed in Table 4.2 will be considered industry incumbents; all other firms will be considered industry non-incumbents.

Legitimacy: as explained in the previous chapter, the legitimacy of an innovation will be assessed in terms of the public's awareness of its present and future, performance and price, relative superiority or inferiority. Data will be collected through a structured content analysis of the media items described earlier. Instructions for coding and an example coding sheet are found in Appendix 2.

As the instructions describe, each media item will be read for any of the "key" expressions (and similar) found in Table 4.1 (a replica of the table will be attached to the instructions). Each time one of these expressions is identified, it will be recorded on the coding sheet along with other essential descriptive data and some control/bookkeeping data. Table 4.1 will also be used as a reference for coding the MD and PT of each innovation. The incumbency of the innovating firm will be assessed against the list of industry incumbents (described above). Incumbents will be coded "1," and non-incumbents will be coded "0."

The instructions direct the reader to look for answers to eight questions. Each question investigates one of the eight aspects of legitimacy expressed in the hypotheses developed previously. To help avoid fatigue, the reader is not asked to assert "yes" or "no" to each and every question for each and every innovation, but to merely read each article attentively for descriptions of an innovation's relative performance and price characteristics, and to then categorize the article's descriptions under the appropriate column headings. A subsequent section of this chapter discusses validation of this technique in greater detail

Design

Kerlinger (1986) observed that "there are times when, in the judgement of the researcher, it is necessary to treat a continuous variable as a nominal variable. For example, it may be possible to measure a potentially continuous variable only in a crude way, say, having an observer judge whether or not objects possess or do not possess an attribute" (149).

While it might be possible that competence enhancement and destruction, incumbency, and legitimacy are all inherently continuous variables, in this study each has been developed as a categorical variable. This choice, though prudent considering the exploratory nature of this dissertation, limits options concerning statistical methodology. Assessing the relationships among categorical variables is accomplished non-parametrically through the analysis of frequencies, or contingency analysis. The following design adheres to the most general and conservative suggestions of Kerlinger (1986), Lapin (1981), and Reynolds (1977 a/b).

Hypothesis 1a will be tested by constructing a two-dimensional, 2x2 frequency table (Table 4.3). Since Morphological Analysis is a forecasting technique and forecasting is conceptually the same as prediction, the MD0-MD>0 dichotomy will be presented along the vertical (independent) dimension, and the incumbent/non-incumbent dichotomy will be presented along the horizontal (dependent) dimension. In each quadrant, the frequencies of the respective intersections of the two variables will be tabulated from the coded data; the quadrant corresponding to competence-enhancement and incumbency will be tabulated as the number of cases where MD was coded as 0 and MFRINC was coded as 1, and so forth for the other quadrants. These tabulations represent actual frequencies (F_a).

Table 4.3. Contingency Table for Hypothesis 1a.

	Incumbent (MFRINC 1)	Non-Incumbent (MFRINC 0)
MD 0	F_a (MD 0, MFRINC 1)	F_a (MD 0, MFRINC 0)
MD>0	F_a (MD>0, MFRINC 1)	F_a (MD.0, MFRINC 0)

Next, the expected frequency (F_c) of each quadrant will be calculated per Lapin (1981) by the formula

$$F_c = \frac{\text{Row Total} \; \text{x} \; \text{Column Total}}{n}$$

and then chi-squared will be calculated as

$$\chi^2 = \sum \frac{(F_a - F_c)^2}{F_c} \quad \text{[sic]}$$

A test for independence, or examination that the actual frequencies in the table are significantly different than the frequencies that would be expected by chance, will be conducted by comparing the calculated chi-squared to standard table values at alpha .10, .05, and .01 where degrees of freedom (df) is calculated as

$$\text{df} = (\text{Rows} - 1)(\text{Columns} - 1)$$

The measure of association (strength of the relation) will then be assessed by calculating the Coefficient of Contingency, C:

$$C = \sqrt{\frac{\chi^2}{\chi^2 + N}}$$

The remaining hypotheses will be tested similarly. Hypothesis 1b (as well as the remaining "b" hypotheses) will be tested by constructing a two-dimensional table, but here the predictor variable (PT) will have four categories, as there are four phenomenologically distinct types of possible MD 1 innovations.

The table for Hypothesis 2a (Table 4.4) will be constructed showing MD 0-MD>0 along the vertical dimension, and another dichotomy will be presented along the horizontal dimension: whether or not the media items reported the range advantage (future v. present, as appropriate) of the innovation. The upper left quadrant will be calculated as the frequency of cases where the MD was coded 0 and NOWBETR was coded 1; the upper right quadrant will be calculated as the frequency of cases where the MD of the innovation was coded 0 and NOWBETR was left blank (defaulted to 0), and so forth. In this way the table is crafted to represent the precise assertion of the hypothesis; that in aggregate, the public is more aware that lead-acid batteries are performing better in electric vehicles than it is aware that competence-destroying options will perform better in the future.

Table 4.4. Contingency Table for Hypothesis 2a.

	Advantage Reported	Advantage Not Reported
MD 0	F_a (MD 0, NOWBETR 1)	F_a (MD 0, NOWBETR 0)
MD>0	F_a (MD>0, THENBETR 1)	F_a (MD> 0,THENBETR 0)

This assertion might seem to be a trivial or even obvious one, but again, hypotheses 2a through 5b are each intended to investigate one aspect of an overall pattern of cogntive legitimation and/or its obstruction, assuming nothing about the proportionality of media coverage and actual industry activity. In this regard, the statistical evaluation of each hypothesis will contribute to an ensuing discussion of the overall pattern.

As well, technical data regarding the present performance and theoretical limitations of many electrochemical devices is available. This and other technical data will help provide the basis for an additional, albeit qualitative, analysis of the industry. This analysis and discussion should be illuminating and, depending on the results of hypothesis testing, could be quite extensive.

Validity and Reliability

Validity and reliability are serious concerns in any study. The following discussion adopts the terminology of, and addresses the concerns expressed in, Cook and Campbell's (1979) Quasi-Experimentation: Design and analysis issues for field settings.

Construct validity addresses the concern that operationalizations might be underrepresented or contain surplus irrelevancies. That is, measures might not fully capture the intended meaning of the referent constructs, and/or they might partially capture other constructs in ways that make interpretation difficult or even specious. Earlier discussions indicate at length some of the precautions taken in this regard; specifically, preoperational explication has been both careful and conservative. A full morphological analysis of the present research (and hence, functional and technological) problem was completed before continuing with the study in order to gain confidence, by example, that operationalizations of competence enhancement and destruction make sense. Explication of industry incumbency (SIC) was accomplished in accordance with the strongest precedent in the Management of Technology literature, which is most relevant to the main issues. Measures of legitimacy are highly specific to the present research question, but highly-tailored legitimacy measures are common to research in institutional theory.

Employing multiple measures of constructs is an important way to gain confidence in the validity of a construct. In this study, eight specific measures of legitimacy are included in as many hypotheses; similarly, these hypotheses morphologically dimensionalize competence enhancement and destruction in two different ways. However, industry incumbency is measured in only one way. Though this is well-precedented and adequate at the present stage of development, intuition suggests that the construct is multidimensional, especially where the enhancement and/or destruction of competences/technologies is at issue. Should initial tests fail and/or prove difficult to interpret, it might be wise in subsequent phases of analysis to revisit this issue.

Using nominal measures to operationalize constructs invites the inclusion of surplus irrelevancies. However, considering the present state of theoretical development, more rigorous operationalizations are unnecessary and possibly inappropriate. The basic research question is exploratory in nature and fundamental patterns are of first interest.

Statistical conclusion validity is another main concern, which considers whether or not it is reasonable to presume that test results reflect true covariation. Here, the power of the test is important. Fortunately, in this study the determinants of power are not problematic; the sample size is large, the effects are theoretically strong, and alpha levels are standard choices.

It is important to consider possible violations of test assumptions. Assuming the adequacy of using nominal variables, frequency/contingency analysis and the goodness-of-fit chi-square is the most commonly accepted and rigorous method/statistic available by which to ascertain statistical covariation. The measure of association (C), on the other hand, was deemed best of about ten choices (Reynolds, 1977a/b) because its assumptions best match this study while its limitations are either manageable or avoided: it addresses the main concern (attenuating chi-square for sample size); it is slightly more accurate; it is not hypersensitive to table dimensions; it avoids mathematical complications that are irrelevant to the present design; it does not mandate an iterative procedure that would mandate initial judgements about association; and importantly, it is not limited to two-dimensional, two-by-two tables.

Since the method of inquiry used in this study is roughly analogous to obtaining questionnaire data from media participants, random heterogeneities of respondents is a possible threat to statistical conclusion validity. For example, success of the electric vehicle industry as a whole will almost certainly cause a migration of jobs from the U.S. midwest (especially Michigan) to the west coast (especially California), while a primary concern in the population centers of the northeast is not the exportation of jobs, but the exportation of pollution from the automobile tailpipe to the smokestacks of coal-burning electric utilities. Geographical locale of respondents might moderate media patterns, as might media type (e.g., newspaper v. trade journal), and so forth. Initial test results and an acquired familiarity with the raw data will indicate the advisability of subsequent analyses of this type.

Of course, reliability is a crucial element of statistical conclusion validity. The above ameliorations to the most important threats are likewise ameliorations to many reliability concerns, but the following observation is particularly salient now. The morphological analysis and matrix (Appendix) was developed by an experienced engineer in strict accordance with the rules of the technique, and then iteratively corroborated over a period of several months with (a) a full professor of industrial engineering, IEEE fellow, and college dean, and (b) a full professor of chemistry with special expertise in electrochemistry.

Of greater concern is the reliability of the coding instrument and general method. Here, a trial run will first be conducted with a doctoral candidate, who will code ten articles for the purpose of identifying general ambiguities and points of confusion. After necessary adjustments are made, five doctoral students will each independently code 25 articles, of which 10 will be common to each coder. These ten will constitute a data base by which to asses the reliability of the instrument among the coders, and the other 75 articles (the 15 peculiar to each of the five coders) will constitute a data base by which to assess the reliability of the instrument between the coders and the author. If in both cases a reliability of .7 (Nunnaly, 1977) is not achieved the instrument will be improved and the above technique will be iterated until reliability is achieved.

Internal and external validity are not main concerns in this study. Internal validity is not a main concern because only statistical association, not causality, is assumed. External validity is not a main concern because it is well-known in the Management of Technology literature that research of this type is idiosyncratic; that is, though technology cycles are sound general frameworks, detailed findings are likely to differ across research settings, especially across major sectors such as assembled products v. non-assembled products v. services. The analysis of this issue will undoubtedly be rich but presumptions about generalizability will be modest.

Summary

It is important to note that research in technology cycles is almost always retrospective or historiographical. The literature's main strength lies in its penetrating richness, not in its methodological rigor. In this light, the present study has two methodological strengths. One, while maintaining the opportunity for almost unlimited richness, it is oriented towards the future, or at worst a real-time understanding of an extremely important contemporary dynamic. Two, the research design is a modest increment, not decrement, in rigor. Contingency analysis of nominal variables is not a sophisticated technique, but it is an objective way of ascertaining fundamental patterns in data that can then be assessed, with reasonable confidence, in more qualitative detail.

The analysis and discussion presented above, while not conducted at a level of sophistication that is beyond the grasp of most business strategists, is technically accurate and is representative of the fundamental premise of this dissertation: that the structure of technology, or technological know-how, is a "real" structure that influences industry evolution within, and transitions between, overlaying socioeconomic structures.

This view is not predominant in the Strategic Management literature, though it is a common inference in the Management of Technology literature. Assessing the interface between these fields is a growing concern and this dissertation hopes to add value to that dialogue. The variables, measures, and tests described in this chapter are coarse-grained and hope to assess basic relationships among constructs which have not been empirically examined in the combination proposed.

CHAPTER 5: ANALYSIS

This chapter is divided into two sections. First, the results of the instrument validation process are presented. The results indicated that the technique and coding instruments were reliable. Second, the results of testing each hypothesis are presented which, on the whole, varied greatly in terms of statistical strength and fundamental interpretability.

Instrument Validation

Validating the reliability of the measuring instrument (coding sheet) and associated materials (instructions and tables) was conducted in two phases. First, a dry run was made with a doctoral candidate. About thirty minutes were initially taken to explain theoretical essentials as well as the research scenario and design, though specific propositions were not divulged. The coder then coded ten articles. Afterwards, the coder was asked to explain the reasoning behind each coding decision. Without exception the coder verbalized decision-making algorithms that precisely adhered to instructions. The coder then offered suggestions on how to improve the materials, which resulted in cleaning up the list of incumbents, rearranging the table of devices and morphological measures so as to not confuse the basic idea that lead-acid batteries were being compared to anything/everything else and vice versa, and rearranging parts of the coding instructions in the same vein. The Appendix exhibits the improved, final coding instructions.

In the second phase each of five doctoral students coded 25 articles. As in the first phase, each student was first trained for about thirty minutes. No student had any significant problems during the subsequent coding process and each completed the task within ninety minutes.

Ten articles were common to each coder's package (not the same articles used during the first phase), affording the opportunity to calculate/estimate their interrater reliability. Here, Nunally (1978) was adamant in asserting that in the development of any new instrument, coefficient alpha (Cronbach's Alpha) should be calculated and reported as the foundation of an assessment of reliability, but that at least one other method should also be employed as a double-check. In the following analysis the following statistics are reported: alpha (and standardized alpha), the correlation between forms of a split-half calculation, and the estimated reliability (and unbiased estimate) of parallel forms.

For the entire data base of the ten articles commonly coded (n = 74), alpha was .9980 (standardized alpha was the same); the correlation between forms was .9967; and the parallel forms estimate was .9980 (the unbiased estimate was .9981). The main reason for these remarkably high figures became apparent after conducting a superficial examination of the results of coding Morphological Distance (MD), Phenomenological Type (PT), and manufacturer incumbency (INC). Agreement among all five coders on all three measures was 100%, except for one occasion where one coder inferred (probably) too much information from an obscure description of a fuel cell and coded an MD and a PT where the other four coders could not make any specific determination.

Subsequently, these three measures were temporarily removed from consideration and the same procedure was performed considering only the eight measures of legitimacy (n = 58). Here, alpha was .8510 (standardized alpha was .8582); the correlation between forms was .8072; and the parallel forms estimate was .8510 (the unbiased estimate was .8562).

The hurdle was raised one more time by considering only those articles that were controversial. That is, three articles that described various power types, but where every coder answered "no" to each of the eight legitimacy questions, were temporarily removed from consideration. This level of scrutiny was beyond the requirements of this study, because non-controversial (noncomparative) descriptions of power types do provide data that are meaningful in terms of the propositions and hypotheses under present consideration. Nevertheless, in this strict test (n = 51) alpha was .8455 (standardized alpha was .8526); the correlation between forms was .7995; and the parallel forms estimate was .8455 (the unbiased estimate was (.8517).

As an additional check, the author coded the same ten articles independently and the analysis was repeated using the data from all six coders. Results of coding MD, PT and INC were the same as described above. Analysis of only the legitimacy measures (n = 58) yielded an alpha of .8932 (standardized alpha was .8954); the correlation between forms was .8535; and the parallel forms estimate was .8932 (the unbiased estimate was .8970). When considering only the controversial articles, alpha was .8892 (standardized alpha was .8912); the correlation between forms was .8479; and the parallel forms estimate was .8892 (the unbiased estimate was .8937). Here, it was also gratifying to note that the author had not overlooked any item that any other coder had found; in other words, in no instance was the author the cause of missing data.

The fifteen articles singularly coded by each coder constituted a data base of 75 articles, against which reliability could be calculated/estimated between the five coders (as a group) and the author (n = 649). Results were highly consistent with the above discussion. Considering all measures, alpha was .9968 (standardized alpha was the same); the correlation between forms was .9937; and the parallel forms estimate was .9968 (the unbiased estimate was the same). Temporarily removing MD, PT and INC from consideration (n = 523), alpha was .9097 (standardized alpha was .9101); the correlation between forms was .8349; and the parallel forms estimate was .9097 (the unbiased estimate was .9100). More straightforward correlations were calculated as well. For legitimacy measures only, the Pearson and Spearman coefficients were both

.8349, noticeably equal to the correlation between forms. After removing five non-controversial articles from consideration (n = 379), alpha was .9034 (standardized alpha was .9037); the correlation between forms, Spearman Coefficient, and Pearson Coefficient were all .8244; and the parallel forms estimate was .9024 (the unbiased estimate was .9039).

Finally, when only two coders are being considered, coefficient Kappa is an appropriate measure of reliability (Brennan & Prediger, 1981). Coefficient Kappa was therefore calculated considering the author and the other five coders, as a group. For the data base of 75 articles, Kappa was .9273; when only the legitimacy measures were considered, Kappa was .8339; when the five non-controversial articles were removed, Kappa was .8233.

Nunally (1978) stated "What a satisfactory level of reliability is depends on how a measure is being used. In the early stages of research on predictor tests or hypothesized measures of a construct ... reliability of .70 will suffice ... For basic research, it can be argued that increasing reliabilities much beyond .80 is often wasteful of time and funds" (245). Though using time and funds efficiently is not a main issue in the successful completion of a dissertation, Nunally's statement otherwise applies here. Even overly-strict examinations of the most suspect portion of the instrument indicated that reliability was comfortably above both .70 and .80.

Nevertheless, it was important to pursue explanations for the coding disagreements, which upon cursory examination seemed to occur within certain articles. Here, it became very useful to the analysis that during their training session, the coders had been implored to liberally mark up their copies of articles as they read them; these markings clearly indicated what triggered many coding decisions. It was a simple task to isolate the analysis of disagreements to not only individual articles, but to individual sentences. For example, in the December 20, 1993 edition of Automotive

News, an article reported "Delco Remy and W.R. Grace also have contracts to explore lithium polymer, which the USABC sees as the best long-term hope for an inexpensive battery offering gasoline-like performance." Here the inference (perhaps) is that lithium polymer batteries will be cheaper than lead-acid batteries will be in the future (THENCHEP=1), but the performance comparison is nil-to-confusing (THENBETR=?) unless one knows that any battery that approaches gasoline-like performance will still be a huge improvement over lead-acid batteries (assuming, also, that "gasoline-like performance" infers range.)

On a few occasions articles contained internal contradictions when indicating the timing of an innovation. In the Dec 14, 1994 Christian Science Monitor, for example, an article read "100 miles ... that's all you'll get from the lead acid batteries used in most of today's electric-vehicle prototypes ... Some breakthrough may be on the way, though ... [several paragraphs later]... a NiMH cell has about twice the 'energy density' of Impact's lead-acid battery pack.. That translates into ranges of as far as 200 miles". One reader might interpret this passage as saying that a superior NiMH cell is presently available or sufficiently imminent to be considered available (NOWBETR=1), while another might interpret the present-tense verbiage as alluding only to its phenomenological potential, and assess the innovation's availability as still not so imminent (THENBETR=1). (In truth, as of this writing no known electric vehicle can travel nearly 200 miles on one charge under realistic conditions). Most disagreements could be traced to verbiage such as the above, though of course there were occasional oversights as well (though again, never by the author).

In short, media descriptions were sometimes noisy, and the instrument did not possess the fidelity by which all sources of noise could be removed. However, it was deemed unlikely that these types of noise would systematically bias the results of the present study, especially since coding disagreements were mostly isolated and relatively few. Though the propositions developed in this dissertation assert that biases exist in the public media, one must concede that a certain level of journalistic imprecision (ambiguous terminology, unintended contradictions, syntactical anomalies, etc.) is a source of random error (hence self-correcting, especially in a large sample), not systematic error.

To summarize, calculations/estimates of the reliability of the instrument as a whole were highly acceptable, and harsher examinations focusing on the most suspect portion of the instrument indicated acceptable instrument reliability, even when taken to a level of scrutiny that was beyond the intent of this study. Delving into the sources of coding disagreements suggested that while the instrument is imperfect, much error is inherent in the nature of the data, and will probably be random. The conclusion drawn from the instrument validation process was that the technique and instruments were sufficiently reliable to allow continuation of the study.

Test Results

Hypothesis 1a. Again, Proposition 1 reiterated one of the strongest contentions of the Technology Cycles literature: that industry incumbents make competence-enhancing innovations, and that industry non-incumbents make competence-destroying innovations. Hypothesis 1a tested this by operationalizing industry incumbency as those firms with 3691 as their primary SIC; competence-enhancement -v.- destruction was operationalized as the MD 0/MD>0 dichotomy.

Table 5.1 presents the data which was used to test H1a. In the media items, it was found that three MD 0 innovations were being pursued by industry incumbents, each by a different incumbent (Exide, Gates, and GNB). Twenty-one MD>0 innovations were being pursued by incumbents; eight manufacturers (Duracell, Eagle-Picher, Eveready, Exide, GNB, Gates, Ovonic, and Sanyo) accounted for all 21. (In other words, the frequency presented in this cell denotes the total number of unique

Table 5.1. Data for H1a.

	MFGINC = 1	MFGINC = 0
MD 0	3	24
MD>0	21	101

combinations of manufacturer and specific innovation. Exide, for example, was pursuing Sodium Sulfur, Nickel-Metal Hydride, and Nickel-Iron batteries, accounting for three of the 21 combinations indicated). Twenty-four MD 0 innovations were being pursued by as many non-incumbents (Table 5.2). One-hundred and one MD>0 innovations were being pursued by 68 different non-incumbents (Table 5.3). Altogether, 88 firms were reported.

Test statistics for this and all subsequent tables were calculated in both their raw (e.g., Table 5.1) and standardized forms. Standardizing frequency tables is accomplished by assuming that each marginal (row) n = 100, and then transforming the raw data in each cell into a percentage. (In Table 5.1, for example, the marginal n for the top row is 27 (3+24). The 3 was transformed into 12.5 since 3 is 12.5% of 27, and so forth). From there, test statistics are calculated in the same way as they are for raw data. This procedure helps ameliorate distortions in the measure of association (C) caused by skewed distributions, and facilitates comparisons among tables with different N's (Reynolds, 1977 a/b).

The test statistics for H1a corroborated what seemed apparent from merely observing the raw data: the pattern of innovation being pursued by incumbents was not significantly different than the pattern of innovation being pursued by non-incumbents; i.e., there was no statistical association between MD (0 or >0) and MFGINC. For the raw data, chi-square was .61 (C = .06), well under the thresholds needed to reject the null at alphas .01, .05, or .1 (at df = 1, these thresholds were 6.635, 3.841, and 2.706,

Table 5.2. Non-Incumbents Pursuing MD 0 Innovations.

Manufacturer	Primary SIC or Country of Origin
Asea-Brown Boveri*	3612
BDM	7371
Bellcore*	8711
CMP	3843
CSIRO	Australia
Delco*	3694
Electrosource*	8731
General Motors*	3711
Genesis	3548
Globe-Union*	3714
Horizon	8731
Japan Storage Battery*	Japan
Johnson Controls*	3822
Mitsui	5051
Norvik	Canada
Optima	3714
RWE	Germany
Silent Power	Great Britain
Sonnenschein	Germany
Tlaxcala	Mexico
Trojan*	3691
Unique Mobility*	8731
Varta*	3999
Westinghouse*	3612

respectively). Standardizing the data yielded a chi-square of 1.48 (C = .08), still well below all three thresholds.

Since the literature so strongly (practically unanimously) supported proposition 1 and H1a, this surprising result begged further examination before continuing with the analysis. One possible reason the test failed was poor operationalization of variables. Here, the morphological distinction still seemed rather obvious; lead-acid batteries (which defined MD 0) were most certainly the automotive paradigm's dominant design for providing electric power in all types of automobiles. If industry incumbency were operationalized poorly, though, some of the firms designated incumbents should have

Table 5.3. Non-incumbents Pursuing MD>0 Innovations.

Aerovironment (2 innovations)
Alcatel (1)
Allied Signal (1)
Anglo-AEG (2)
Asea-Brown Boveri (2)
AT&T (1)
BAE (1)
Ballard (2)
Battery Technology Center (2)
Bellcore (1)
Daido (1)
Delco (2)
DEMI (1)
Directed (1)
Dunlop (1)
ECD (1)
EIC Labs (2)
Electric Fuel (1)
Electrosource (1)
Energy Partners (1)
Energy Resources (5)
Ergenics (1)
Ford (1)
Fuel Electric (1)
Fuji (1)
General Motors (1)
Globe Union (1)
Gold Peak (1)
Grace (2)
Gulf & West (1)
Hewlett-Pakard (1)
Hitaci Max (1)
Hope (1)
H-Power (2)
Hydro-Quebec (2)
Inco (1)
International Fuel Cell (2)
Japan Storage Battery (1)
Johnson Controls (2)
Lockheed (1)
M-C Power (1)
Matsushita (2)
3M (2)
Motorola (1)
Nel Nithium (1)
Pentastar (1)
Powercell (1)
RCI (1)
Rolls-Royce (1)
Rover (1)
SAFT (8)
Samsung (1)
Schatz (1)
SEA (1)
Silent Power (1)
Sony (1)
Sovlux (1)
SRI (3)
Toshiba (1)
Trojan (1)
TV Station (1)
UCAR (1)
Valence (2)
Varta (3)
Volta (1)
Westinghouse (3)
ZincAir (1)
Zteck (1)

been designated non-incumbents, and vice versa -- especially where the lower left and upper right quadrants of Table 5.1 were concerned. Concerning the lower left quadrant, it was perhaps the case that any or all of Duracell, Eagle-Picher, Eveready, Ovonic, and Sanyo (the five incumbents not also pursuing MD 0 innovations) were not incumbent to the production of lead-acid batteries, compared to firms more traditionally tied to the extant automotive paradigm.

To gain a better understanding of this possibility, these firms were researched further, by referring to the business references cited earlier. Some descriptions of Duracell, Eagle-Picher, Eveready, and Ovonic seemed to lean towards the specialty, consumer market for storage batteries (typically non-lead-acid batteries), but this assessment was subjective and no information clearly suggested that automotive products were beyond their ken or present efforts. Sanyo was clearly indicated as being attentive to the automotive market. Pending additional theoretical development and a detailed, individual assessment of firms, analyzing this subset of manufacturers did not make obvious any within-SIC distinction of which should not be considered incumbent.

Also, after additionally researching and examining the non-incumbents pursuing lead-acid innovations (Table 5.2), it was difficult to discern a consistent pattern (in their SICs or nationalities) that suggested a better definition of industry incumbency than that which was used. (One mistake did become apparent. In Standard & Poor's industrial manual, Trojan's primary SIC was discovered as being 3691, so this firm probably should have been considered to be an incumbent. However, this oversight did not affect the conclusions and interpretations in any of the following discussions). If anything, this group seemed extremely diverse. Furthermore, twelve of these firms (asterisked in the table) were pursuing MD>0 innovations as well as MD 0 innovations, which would weaken the argument that even firms like GM and Delco should have been considered incumbent. Finally, on the speculation that the non-U.S. firms were primarily manufacturers of storage batteries (the original list of industry incumbents, taken from Ward's directory, included only U.S. firms), the Directory of foreign manufacturers in the United States (Arpan & Ricks, 1993) was consulted; there was no overlap between the directory's list of 3691 manufacturers and Table 5.2. In sum, it did not become apparent that the operationalization of industry incumbency was incorrect.

Rather than pursue operationalizations further, it seemed much more urgent to pursue the observation that of the 45 firms incumbent to SIC 3691, only 8 appeared at all in several thousand media items concerning electric vehicles, a scenario which was unquestionably opportune for manufacturers of storage batteries in general, simply because of the direct link from phenomenological function to user functionality. In other words, it became important to speculate as to the representativeness of the reported eight incumbents.

In an earlier discussion, it was conceded that some efforts at innovation might go unnoticed by the public media for any of several reasons. In the case of storage battery industry incumbents, who on the whole could be expected to attract media attention if it was desired, especially in an important industrial scenario where their product-type was the most acute technological bottleneck, unreported breakthroughs in-the-making would likely be those cloaked in secrecy (i.e., proprietary programs). However, on the strength of the Technology Cycles literature, it was at least as likely that the reason why many incumbents' activities went unreported was because they weren't very newsworthy (i.e., incremental improvements to existing products or no real innovative activity at all).

In this light, H1a was re-examined making assumptions about the activities of the 37 unreported incumbents. A calculation was made to see how the innovation activities of these firms would have to be distributed in order for the hypothesis to have passed at alpha = .05. (This procedure was conceptually identical to solving the "file drawer" problem in meta-analysis (Hunter, Schmidt, & Jackson, 1982), where the researcher is advised to calculate how many unpublished, non-significant findings of a presumed relationship between variables would have to be "still out there" (unreported publicly), in order to change the conclusion inferred by the data that was actually on-hand.) Through trial-and-error, it was calculated that if only 17 of the 37 unreported incumbents were each pursuing one MD 0 innovation (on the generous assumption that they were all attempting to innovate somehow) and had been reported, and that if each of the other 20 were pursuing one MD>0 innovation and had been reported (hence adding these numbers to the appropriate cell frequencies in the first column in Table

5.2), then the null hypothesis would have been rejected at alpha = .05 (chi-square = 4.20, C = .15).

Of course, a devil's advocate might also have speculated about the possible number and distribution of unreported, non-incumbent activities, but the population of non-incumbents was infinite for all practical purposes. Suffice it to say that the statistical impact of unreported incumbent activity could have been either offset or exacerbated by the impact of unreported non-incumbent activity. Either way, the statistical conclusions of the tests of H1a were arguable. Intuition and the above calculation suggested that reported incumbent activity was not representative of the total population of incumbents.

Summarizing the analysis of H1a, there was no statistical association between whether an innovation was competence enhancing or competence-destroying, and industry incumbency. However, the test statistic became suspect when considering the representativeness of the small number of incumbents reported. In an earlier chapter it was asserted that it is more accurate to say that observing media activity is to observe a pattern of legitimation first-hand, than it is to say that observing media activity is to observe actual industry activity second-hand. What might seemed to have been a fine research distinction at the time might be an understatement in some scenarios. The statistical tests of H1a might have failed, ironically, because of an understandable selection bias in the media -- a bias towards newsworthiness.

Hypothesis 1b. H1b asserted that the pattern of competence-destroying innovation being pursued by incumbents would be different than the pattern being pursued by non-incumbents, operationalizing discontinuities in the most abstract sense and for the most general case: by holding MD constant at 1 (the literature asserted that most discontinuous innovation would occur at the morphological frontier) and testing the pattern of innovation activities across the four phenomenological parameters (Phenomenological Types).

Table 5.4 presents the data used to test this hypothesis. It was immediately apparent that the marginal (row) frequencies were highly skewed. There were 38 PT1 innovations, 2 PT2 innovations, and no PT 3 or PT 4 innovations. At face value, some inferences could be drawn from this table. First, it highlighted the enormous importance of the ReDox phenomenon in the development of an electric vehicle power source; perhaps this was the "core competence" of concern, the technology that demanded deep and hopefully firm-specific expertise needed to sustain competitive advantage and/or technological leadership. As such, it was also suggestive of a key technological bottleneck, corroborated by the observation that every innovation of MD>1 was defined by a change in ReDox plus a change in at least one other parameter. A third, perhaps weaker inference was that during the period of time in question, it was commonly known or at least taken for granted that a lead-acid ReDox did not possess the theoretical and/or practical phenomenological potential to really solve the electric vehicle range problem -- at least in the long-term. Only two other firms (one incumbent and one non-incumbent) were pursuing a PT2 innovation, which differed from the dominant design only in the commonality of the electrodes and the reactant materials (a Sealed, Bi-polar Lead-Acid battery).

On the other hand, the skewness of the data did much to injure the interpretability of statistical tests. More specifically, it is a rule of thumb in the analysis of nominal data that when expected frequencies are below five, the probability of Type II error (accepting the null hypothesis when it is false) increases because the contribution to the total chi-square by such low frequencies is small, and more than offset by the concomitant degree of freedom incurred by the presence of the row, which raises the threshold which must be surpassed in order to reject the null (Reynolds, 1977

Table 5.4. Data for H1b.

	MFGINC = 1	MFGINC = 0
PT1 (ReDox)	10	28
PT2 (Commonality)	1	1
PT3 (Temperature)	0	0
PT4 (Regeneration)	0	0

a/b). When such occasions arise, the researcher is advised to (a) collapse categories, or (b) interpret the low frequency rows as "outliers", remove them from consideration, and proceed normally, or (c) accept the increased likelihood of Type II error (since it is the more conservative type) and make appropriately judicious interpretations of test results.

However, in Table 5.4 six of eight expected frequencies were below five, and it became apparent that all of H2b, H3b, H4b, and H5b would suffer similarly. None of the above options would enable any meaningful chi-square test. Therefore, it was evident that in order to pursue all "b" hypotheses beyond face value interpretations like the one above, a different approach to the concept of Phenomenological Type had to be considered.

Again, holding MD constant at 1 and testing across individual parameters was developed as the most fundamental and rudimentary approach to testing patterns across Phenomenological Types. While this was appropriate when developing propositions because it described the most general case and theoretically probable scenario, it was also argued during proposition development that once a morphological matrix was fully explicated, it would also be appropriate to consider all devices of identical combinations of phenomenological options as being the same Phenomenological Type. For example, all MD2/PT1/PT2 innovations would be the same Phenomenological Type, as would be all MD2/PT1/PT4 innovations, and so forth. The reason it would not be wise to operationalize Phenomenological Type this way *ex ante* is because in any matrix of any appreciable size, the number of permutations is large and unwieldy. *Ex post*, after a matrix is developed and realistic permutations are assessed, operationalizing Phenomenological Type this way becomes not only manageable, but preferable because of its improved precision and inclusion of all plausible morphs.

Towards that end, once coding of all articles was completed, and once the data was reviewed, it became apparent that no electrochemical innovations were being pursued that had not been previously identifed and morphologically explicated. At that point, it became appropriate to re-operationalize Phenomenological Type according to the following categories, which represent groupings of identical combinations of options. In order to avoid confusion with the prior operationalization, Types were designated alphabetically instead of numerically. Also, in order to make subsequent discussions much less cryptic, nomenclatures were arbitrarily created.

PTA (MD 0): "Lead Acid Batteries;" the dominant design.

PTB (MD1/PT1): "Other ReDox Batteries." This PT depicts devices which differed from the dominant design only by the choice of ReDox materials: reports were found of Nickel-Cadmium, Nickel-Iron, Nickel-Metal Hydride, Nickel-Zinc, Zinc Bromide, and Zinc Chloride batteries.

PTC (MD1/PT2): "SBLA." The only reported device of this type was the Sealed, Bi-Polar Lead-Acid Battery, a lead-acid battery where the electrodes and the reactant materials are not one-and-the-same.

PTD (MD2/PT1/PT3): "Hot Batteries." This PT depicts devices that, because of the choice of ReDox materials and associated electrolyte, also require a thermal control system in order to maintain an important material in a molten state: there were many reports of Lithium Carbon, Lithium Polymer, Lithium Iron (Di)Sulfide, Lithium Vanadium, Nickel Hydrogen, Sodium Metal Chloride, and Sodium Sulfur batteries.

PTE (MD2/PT1/PT4): "Zinc Air." This PT depicts devices that contain a ReDox material that can not be electrically regenerated, at least not practically at the vehicle. Instead of "plugging in" the vehicle to "refuel", the operator must stop at a store (equivalent to the present filling station concept) and exchange cassettes, or modules, of reactant materials. The only device of this type reported was a Zinc-Air Battery.

PTF (MD2/PT1/PT2): "Regenerative Fuel Cells." This PT depicts devices where the ReDox is not lead-acid, and electrodes are not the reactant materials. The nomenclature does not actually delimit the PT to fuel cells; it merely reflects the fact that only the Regenerative Solid Polymer Fuel Cell was reported.

PTG (MD3/PT1/PT2/PT3): "Aluminum-Air." This PT depicts devices where ReDox is not lead-acid, electrodes are not the reactant materials, and a thermal control system is necessary. The Aluminum-Air battery was the only device of this type that was reported.

PTH(MD3/PT1/PT2/PT4): "Common Fuel Cells." This PT depicts devices where the ReDox is not lead-acid, electrodes are not the reactants, and reactants can not be electrically regenerated (at least not at the vehicle). All reported devices of this type fit the most pedestrian term for fuel cells; hence the nomenclature. Reported devices were the Alkaline Potassium Hydroxide, Phosphoric Acid, and Non-Regenerative Solid Polymer fuel cells.

PTI (MD4): "Hot Fuel Cells." This PT depicts the most morphologically distant type of device in the present scenario: non-regenerative fuel cells that require thermal control. Devices reported were the Molten Carbonate and Solid Oxide fuel cells.

It must be reiterated that the above nomenclatures are completely arbitrary and reflect, *ex post*, the specific findings of this study and were chosen only to lubricate subsequent discussions; theoretically, the number of possible devices in each category is essentially infinite.

The obvious danger of reoperationalizing Phenomenological Type in the above manner was the possibility that expected frequencies would only decrease, as raw frequencies should be expected to only be diluted among more rows. However, as subsequent discussions will make clear, this danger was generally more than offset by the ability to consider all MD>0 innovations, not just those of MD1. Doing so not only increased frequencies greatly, but allowed consideration of the entire range of devices pertinent to the study, by including devices of MDs 2, 3, and 4.

Thus, a new column was added to the data base, and all POWRTYPEs were assigned an alphabetical Phenomenological Type. From that point forward numerical PTs were abandoned. Table 5.5 presents the revised view of H1b. Note that since the hypothesis was only concerned with the pattern of competence-destroying (MD>0) innovations, PTA was not considered. (An attentive reader might have noticed that the sum of the numbers in the first column is 20, while in Table 5.1, 21 MD>0, MFGINC=1 innovations were indicated. This and most other counting anomalies were accounted for by the fact that during the coding process, it was sometimes possible to conclude that a device was certainly MD>0, without being able to classify it more specifically (by PT) than that. This and other types of counting anomalies, some of which might have been attributable to human error, appeared to inject about 1% deviation among some tables, which did not affect results). Marginal frequencies immediately made clear that most attempts at competence-destroying innovation were focused on Other ReDox (PTB) and Hot Batteries (PTD), and Common Fuel Cells (PTH). In particular, 19 of 20 incumbent innovations were of these types, as were 85 of the 95 non-incumbent innovations. The non-incumbent pattern seemed to be much more diverse and, as would make sense, all but one fuel cell innovation (PTs F, H and I) was

Table 5.5. Raw Data for H1b, Revised View.

	MFGINC = 1	MFGINC = 0
PTB	10	29
PTC	1	1
PTD	8	43
PTE	0	5
PTF	0	2
PTG	0	0
PTH	1	13
PTI	0	2

being pursued by non-incumbents to the storage battery industry. It was also interesting that the ratio of incumbent-to-non-incumbent PTB activity was about 1:3, while the same ratio of PTD activity was less than 1:5, supportive of the general contention that when being adventurous, incumbents would be more likely to explore the "frontier" of a morphological map (PTB innovations were of MD1) than they would be to make "distant" leaps (PTD innovations were of MD2.) Furthermore, only one incumbent was pursuing an MD 3 (PTG) innovation, and no incumbents were pursuing an MD 4 (PTI) innovation. Conversely, there were thirteen unique combinations of non-incumbent MD 3 (PTH) innovations reported, and 2 unique combinations of non-incumbent MD4 (PTI) innovations were reported.

Unfortunately, test results were not emphatically supportive of these observations. The chi-square of the entire table was 6.34 (C = .23), below the thresholds for alphas .01, .05, and .1 (at df = 7, alphas were 18.475, 14.067, and 12.017, respectively). On the other hand, because of many low expected frequencies, the possibility of TYPE II error here should be appreciated. Subsequently, rows containing cells with low expected frequencies were removed: only PTB and PTD remained in a 2x2 table, where the chi-square was 1.37 (C = .12), which also failed to reject the null. After standardizing the 2x2 table, chi-square was 3.02 (C = .12), which did reject the null at alpha = .1.

Collapsing PTs into MDs 1, 2, 3, and 4 was considered as a means of improving the likelihood of rejecting the null, but doing so would have obfuscated the meaning of PT to such a degree that statistical results would have had dubious interpretability, and probably would have been merely artifactual.

On the whole, then, the statistical association between Phenomenological Type and incumbency was marginal, at best. Also, unlike the analysis of H1a, where assumptions about unreported incumbents shed a different light on the initial findings, similar logic did not pertain here. Unreported incumbent activity would most likely have been of PTA, which was not considered in H1b. Though a subjective analysis of Table 5.5 found a pattern supportive of the hypothetical contention, statistical tests were unable to verify those observations in a convincing way.

Hypothesis 2a. Proposition 2 asserted that the short-term performance advantage of competence-enhancing innovations would be reported in the public media more frequently than the long-term performance advantage of competence-destroying innovations. In H2a, reports of the short-term performance advantage of competence-enhancing innovations was operationalized as the number of times an MD 0 innovation was coded NOWBETR=1, and reports of the long-term performance advantage of competence-destroying innovations was operationalized as the number of times an MD>0 innovation was coded THENBETR=1.

Table 5.6 presents the results. The short-term performance advantage of competence-enhancing innovations was reported less than half the number of times than the future performance advantage of competence-destroying innovations. But

Table 5.6. Data for H2a.

MD 0	NOWBETR=1: 75	NOWBETR=0: 222
MD>0	THENBETR=1: 165	THENBETR=0: 518

obviously, this was largely attributable to the much larger number of reports of all MD>0 innovations; hence the need to assess proportionality, and the right-hand column of the table.

Chi-square for the table was .13 (C = .01), well below the thresholds needed to reject the null. When the table was standardized, chi-square and C both dropped to zero. Without a doubt, there was no statistical association between whether an innovation was competence-enhancing or competence-destroying, and the rate at which its respective performance advantage was reported. The hypothesis was clearly refuted.

Hypothesis 2b. H2b asserted that the public media would report the long-term performance advantage of some Phenomenological Types of competence-destroying innovations less frequently than others. Table 5.7 presents the results. As was discovered in the analysis of H1a, most media attention was focused on Other ReDox (PTB) and Hot Batteries (PTD), though Zinc Air (PTE) and Common Fuel Cells (PTH) garnered what seemed to be non-trivial amounts of attention as well. In both absolute and proportional terms, PTD seemed to fare better than PTB.

Statistical tests supported these observations. The chi-square for Table 5.7 was 20.05 (C = .18), which rejected the null at alpha = .01. Once rows containing low expected frequencies were removed, only PTs B, D and E remained; the chi-square for the resulting 2x3 (df = 2) table was 12.32 (C = .15), which also rejected the null at .01. When this table was standardized, chi-square was 5.08 (C = .12), which was slightly under the threshold for rejecting the null at alpha = .05.

Table 5.7. Data for H2b.

	THENBETR=1	THENBETR=0
PTB	58	240
PTC	1	5
PTD	75	153
PTE	7	20
PTF	2	0
PTG	0	1
PTH	4	17
PTI	0	2

On the whole, then, results indicated that there was a statistical association between the Phenomenological Type of a competence-destroying innovation, and rate at which its long-term performance advantage was reported. Specifically, the future performance advantage of Hot Batteries was reported more frequently (75 reports) than Other ReDox Batteries (58 reports), which were both reported much more frequently than any other type. Proportionately, Hot Batteries fared about twice as well as Other ReDox Batteries.

In terms of the overall assertion of Proposition 2, results of testing H2a and H2b indicated that in absolute terms, competence-destroying innovations got more publicity than competence-enhancing innovations, but that article-for-article they received equitable treatment in terms of the reporting of their respective performance advantages; and that among competence-destroying innovations, firms pursuing Other ReDox and Hot Batteries received a very large portion of the publicity, with Hot Batteries faring best in both absolute and proportional terms.

Hypothesis 3a. Proposition 3 asserted that the long-term performance disadvantage of competence-enhancing innovations would be reported in the public media less frequently than the short-term performance disadvantage of competence-destroying innovations. In H3a, reports of the long-term performance disadvantage of competence-enhancing innovations was operationalized as the number of times an MD 0 innovation was coded THENWORS=1, and reports of the short-term performance disadvantage of competence-destroying innovations was operationalized as the number of times an MD>0 innovation was coded NOWWORS=1.

Table 5.8 presents the results. The long-term performance disadvantage of competence-enhancing innovations was reported about half as many times as the short-term performance disadvantages of competence-destroying innovations. But again, there were many more total reports of competence-destroying innovations, and proportionality was important to consider.

Table 5.8. Data for H3a.

MD 0	THENWORS=1: 30	THENWORS=0: 264
MD>0	NOWWORS=1: 62	NOWWORS=0: 623

Chi-square for the table was .31 (C = .02), too low to reject the null. When the table was standardized, chi-square was .06 (C = .00). Mirroring the results of testing H2a, there was no statistical association between whether an innovation was competence-enhancing or competence-destroying, and the rate at which its performance disadvantage was reported. On this measure, competence-enhancing and competence-destroying innovations fared about the same. The hypothesis was clearly refuted.

Hypothesis 3b. H3b asserted that the public media would report the short-term performance disadvantage of some Phenomenological Types of competence-destroying innovations less frequently than others. Table 5.9 presents the results. Similar to the analysis concerning H2b, most media attention was focused on Other ReDox (PTB) and Hot (PTD) Batteries, and Common Fuel Cells (PTH.) Whereas in H2b there had been seven reports of the future performance superiority of Zinc-Air Batteries (PTE),however, there were no reports that it was presently inferior to Lead Acid-Batteries. Also, whereas in H2b Common Fuel Cells were reported for their future performance advantage four times (resulting in a low expected frequency), here they were reported as being inferior in the short-term seven times (resulting in an adequate expected frequency.) Finally, whereas in H2b Hot Batteries were so clearly favored in both absolute and proportional terms, here the comparison to Other ReDox batteries seemed much less revealing.

The chi-square for Table 5.9 was 18.30 (C = .18), which rejected the null at alpha = .05. Once rows containing low expected frequencies were removed, leaving only PTs B, D, and H, chi-square was 13.18 (C = .15), which rejected the null at alpha = .01. When the table was standardized, chi-square was 19.48 (C = .25), rejecting the null at alpha = .001.

On the whole, then, results indicated that there was a statistical association between the Phenomenological Type of a competence-destroying innovation and the rate at which its short-term performance disadvantage was reported, though this association was largely determined by the way Common Fuel Cells were reported. Otherwise, the contrast between Other ReDox and Hot Batteries, which was so clear in the analysis of H2b, was not so evident here.

In terms of the overall assertion of Proposition 3, results of testing H3a and H3b indicated that in absolute terms, competence-destroying innovations got more publicity than competence-enhancing innovations, but that article-for-article they received equitable treatment in terms of the reporting of their respective performance disadvantages; and that among competence-destroying innovations, firms pursuing

Table 5.9. Data for H3b.

	NOWWORS=1	NOWWORS=0
PTB	23	281
PTC	0	6
PTD	27	201
PTE	0	27
PTF	0	2
PTG	0	1
PTH	7	16
PTI	0	2

Other ReDox, Hot, and Zinc-Air Batteries, as well as Common Fuel Cells, received a very large portion of the publicity. Other ReDox and Hot Batteries were reported most often for their short-term performance disadvantage but proportionately, Common Fuel Cells fared the worst.

Hypothesis 4a. In Propositions 4 and 5, the argument was parallel to that presented in Propositions 2 and 3, but here the dimension of concern was price, not performance. Proposition 4 asserted that the short-term price advantage of competence-enhancing innovations would be reported more frequently than the long-term price advantage of competence-destroying innovations. In H4a, reports of the short-term price advantage of competence-enhancing innovations was operationalized as the number of times an MD 0 innovation was coded NOWCHEAP=1; reports of the price advantage of competence-destroying innovations was operationalized as the number of times an MD>0 innovation was coded THENCHEP=1.

Table 5.10 presents the results. The number of times respective price advantages were reported was about the same. However, proportions were obviously very different. Chi-square for the table was 23.00 (C = .15), which rejected the null at not only alpha = .01, but also at .001. When the table was standardized, chi-square was 5.10 (C = .16), which rejected the null at alpha = .05. There appeared to be a statistical association between whether an innovation was competence-enhancing or competence-destroying, and the rate at which its respective price advantage was reported.

Table 5.10. Data for H4a.

MD 0	NOWCHEAP=1: 47	NOWCHEAP=0: 247
MD>0	THENCHEP=1: 43	THENCHEP=0: 639

This result stood in stark contrast to the results of H2a, which differed from H4a in the consideration of performance rather than price. The standardized chi-square for the tests of H2a were zero; in H4a, chi-square was large enough to reject the null at alpha = .05.

Hypothesis 4b. H4b asserted that the public media would report the long-term price advantage of some Phenomenological Types of competence-destroying innovations more than others. Table 5.11 presents the results. Again, Other ReDox (PTB), Hot (PTD) and Zinc-Air (PTE) Batteries, as well as Common Fuel Cells (PTH) dominated. The number of reports of the long-term price advantage of Other ReDox and Hot Batteries was about the same.

Chi-square for the table was 12.41 (C = .14), which rejected the null at alpha = .1. Once rows containing low expected frequencies were removed, leaving only PTs B and D, chi-square was .18 (C = .02), too low to reject the null. When this table was standardized, chi-square was .08 (C = .02), only lower. There appeared to be no statistical association between the Phenomenological Type of a competence-destroying innovation and the rate at which its long-term price advantage was reported.

Table 5.11. Data for H4b.

	THENCHEP=1	THENCHEP=0
PTB	17	282
PTC	0	6
PTD	15	213
PTE	5	22
PTF	0	2
PTG	0	1
PTH	4	17
PTI	0	2

In terms of the overall assertion of Proposition 4, results of testing H4a and H4b indicated that in absolute terms, competence-destroying innovations got more publicity than competence-enhancing innovations, but that article-for-article, competence-enhancing innovations fared much better in terms of the reporting of their short-term price advantage. Among competence-destroying innovations, Other ReDox, Hot, and Zinc Air Batteries, as well as Common Fuel Cells dominated media attention, but article-for-article they fared about the same in terms of the reporting of their long-term price advantage.

Hypothesis 5a. Proposition 5 asserted that the long-term price disadvantage of competence-enhancing innovations would be reported in the media less frequently than the short-term price disadvantage of competence-destroying innovations. In H5a, reports of the long-term price disadvantage of competence-enhancing innovations was operationalized as the number of times an MD 0 innovation was coded THENEXP=1; reports of the short-term price disadvantage of competence-destroying innovations was operationalized as the number of times an MD>0 innovation was coded NOWEXP=1.

Table 5.12 presents the results. There was obviously a huge disparity in the number of times that MD 0 (lead-acid) innovations were reported as not maintaining their price advantage in the long term, versus the number of times all MD>0 innovations were reported as being more expensive than lead-acid in the short term. The disparity also seemed huge on a proportional basis.

Table 5.12. Data for H5a.

MD 0	THENEXP=1: 4	THENEXP=0: 290
MD>0	NOWEXP=1: 92	NOWEXP=0: 592

Test statistics confirmed these observations. Chi-square of the table was 33.94 (C = .18), high enough to reject the null at alpha = .001. When the table was standardized, chi-square was 11.06 (C = .05), still marginally high enough to reject the null at alpha = .01. Clearly, there was a statistical association between whether an innovation was competence-enhancing or competence-destroying, and the reporting of its respective price disadvantage.

Hypothesis 5b. Finally, H5b asserted that the public media would report the short-term price disadvantage of some Phenomenological Types of competence-destroying innovations less frequently than others. Table 5.13 presents the results. Once more, most media attention was focused on Other ReDox (PTB), Hot (PTD), and Zinc-Air (PTE) Batteries, and Common Fuel Cells (PTH). The most glaring observation was that for the first and only time in any test of a "b" hypothesis, a number in the left-hand side of the table was larger than the number on the right-hand side (at the same PT). Specifically, it was more common to read in a report about a Common Fuel Cell that its short-term price would be prohibitive compared to that of Lead-Acid Batteries, than it was to find no comment at all about the present price. Otherwise, the number of times Other ReDox Batteries were reported as being more expensive than

Table 5.13. Data for H5b.

	NOWEXP=1	NOWEXP=0
PTB	41	258
PTC	0	6
PTD	27	202
PTE	1	26
PTF	0	2
PTG	0	1
PTH	12	9
PTI	0	2

Lead-Acid Batteries was noticeably larger than the number of similar reports of Hot Batteries, which implied a different proportion of these reports as well.

Largely on account of the impact of Common Fuel Cells, the chi-square for this table was 38.02 (C = .25), which rejected the null at alpha = .001. After removing rows with cells containing low expected frequencies PTB and PTD remained; chi-square was .42 (C = .03). After standardizing the table, chi-square was .18 (C = 0). In other words, except for the extraordinary impact of the way Common Fuel Cells were reported, there appeared to be no statistical association between the Phenomenological Type of a competence-destroying innovation and the reporting of its short-term price disadvantage.

In terms of the overall assertion of Proposition 5, H5a and H5b indicated that in both absolute and proportional terms, competence-destroying innovations fared far worse than competence-enhancing innovations in terms of the reporting of their respective price disadvantages. Among competence-destroying innovations, Common

Fuel Cells fared the worst of all on a proportional basis, in fact being the only PT notedmore often as being presently expensive, than not.

Summary

Overall, it is easy to compare and contrast these results, since most test statistics either clearly supported or refuted individual hypotheses.

There were three main issues underlying Propositions 1 through 5. First was the relationship between industry incumbency and competence-enhancement -v.- destruction. The second was the pattern of reports of innovations' performance characteristics, considering the morphological dimensions. Third was the pattern of reports of innovations' cost/price characteristics, considering the morphological dimensions.

There was no statistical association between industry incumbency and whether an innovation was competence-enhancing or competence-destroying. However, the storage battery industry seemed very under-represented in the media items, and the probable reason seemed, ironically, to reverse the interpretation of the test. At face value there seemed to be an association between incumbency and the PT of a competence-destroying innovation, but statistical tests were inconclusive (though these latter tests contained a Type II bias.)

The public media was dominated by reports concerning Lead Acid Batteries, Other ReDox Batteries, Hot Batteries, ZincAir Batteries, and Common Fuel Cells. All other Phenomenological Types of innovations were reported, but in numbers that were generally too low to contribute to the analysis.

Clearly, there was no statistical association between whether an innovation was competence-enhancing or competence-destroying, and rates at which respective performance advantages (H2a) and disadvantages (H3a) were reported. However, there was a statistical association between the Phenomenological Type of a competence-destroying innovation and the rate at which both its performance advantage (H2b) and performance disadvantage (H3b) were reported.

Surprisingly, the pattern concerning reports of price advantages and disadvantages was essentially the opposite. Here, there was a clear statistical association between whether an innovation was competence-enhancing or competence-destroying, and the rate at which its respective price advantage (H4a) and price disadvantage (H5a) was reported. Competence-enhancing innovations fared better in H4a, and better still in H5a.

On the other hand, there was generally a lack of a clear statistical association between the Phenomenological Type of a competence-destroying innovation and the rate at which its price advantage (H4b) and price disadvantage (H5b) were reported. The one very significant exception was that Common Fuel Cells were reported more often for their short-term price disadvantage more often than they were not.

Succinctly, the general pattern did not favor the dominant design for its short-term performance advantage or disfavor it for its long-term performance disadvantage; but it did favor the dominant design for its short-term price advantage, and disfavored its alternatives for their long-term price disadvantages. Looking at the non-dominant design alternatives, the general pattern did favor some Phenomenological Types more than others for their long-term performance advantage and disfavor some Types more than others for their short-term performance disadvantage; the only certainty concerning price was the near-term disfavorability of Common Fuel Cells.

CHAPTER 6: DISCUSSION

Probably the most surprising aspect of the analysis presented in the previous chapter was that the overall pattern seemed so clear. First, it was clear that industry incumbents were, for the most part, not aggressively engaged in the development of a viable electrochemical power source for electric vehicles. The U.S.-based industry did not even provide the impetus behind developing improved Lead-Acid Batteries; only three of the 27 reported MD 0 innovations were being developed by SIC 3691 manufacturers. Second, reports of the relative performance advantages and disadvantages of MD 0 and MD>0 innovations clearly occurred at almost identical rates, while reports of the performance advantages and disadvantages of the different Phenomenological Types of competence-destroying innovations clearly occurred at very different rates. Third, reports of the relative price advantages and disadvantages of MD 0 and MD>0 innovations clearly occurred at very different rates, while reports of the price disadvantages and disadvantages of the different Phenomenological Types of competence-destroying innovations clearly occurred at very similar rates, except for one PT.

This pattern was so clear because while about half of the statistical tests passed by wide margins, the other half failed by wide margins. However, it would be simplistic to point at the bipolarities in the test results and quickly conclude that the media was biased. Rather, it seemed necessary to first develop an assessment of actual industry activity, the technological reality in the prime dimesions of concern, and use it as a comprehensive point of reference. The first three sections of this chapter develop this backdrop, through a relatively qualitative triangulation of three sources of materials, en route to interpreting the pattern of legitimacy presented in the previous chapter. The final two sections synthesize all findings, extend the interpretations, and summarize.

Incumbency

When H1a was tested and analyzed in the previous chapter, the possibility that the operationalization of industry incumbency was incorrect was considered and, though examining the lists of firms participating in the "corners" of the test failed to clearly indicate a better operationalization, the issue was not definitively resolved. When H1b was subsequently tested and analyzed in its original form, however, additional insight became available. There, it became overwhelmingly apparent that PT1 (ReDox) was the key to developing a viable electrochemical device for electric vehicles. Virtually all MD1 innovations were defined by the switch of PT1 options, and every MD>1 innovation included at least the switch of PT1 options. At that time it was argued that ReDox should be considered the core technology, or core competence, of concern. Since the main issue was the enhancement and/or destruction of competences, and since the Lead-Acid ReDox was so clearly part of the dominant design, a stricter but still appropriate (since it was still morphologically and phenomenologically determined) definition of industry incumbency became, at this point of the study, "Manufacturers of electrochemical devices based on the Lead-Acid ReDox".

Theoretically, this definition still invited fuel cells and primary batteries (SIC 3692 as well as SIC 3691) into consideration, but after weighing several practical matters, both fuel cells and primary batteries did become excluded. First, there simply were no Lead-Acid fuel cells. Second, it was argued in the morphological analysis in Appendix 1 that regenerability was always the PT4 option of choice, when it was phenomenologically possible to make that choice. To be consistent with that analysis, and because the inherent phenomenological potential of the Lead-Acid ReDox was low enough to make a primary Lead-Acid Battery an inherently foolish idea (discussed below), SIC 3692 firms were also excluded from consideration. Thus the revised, and in this study final definition of industry incumbency became "SIC 3691 firms primarily engaged in the manufacturing of Lead-Acid Batteries".

Thus each firm previously identified as an incumbent was researched in major business references, for information indicating whether or not it was primarily engaged in the manufacturing of Lead-Acid storage batteries. The following thirteen firms were specifically and uniquely described as being primarily engaged in manufacturing Lead-Acid storage batteries: Charter Power Systems, East Penn, Encore, Exide, GNB, Green, Mixon, New Castle, Palos Verdes, Power Battery, Ramcar, Sanyo, and Standard Industries. Abstract decriptions of other firms did not necessarily mean, of course, that they were not manufacturing Lead-Acid storage batteries at all, but the immediate purpose was to isolate a set of firms that would most intently be concerned about the fortunes of the Lead-Acid ReDox, and thus the fate of their core technological and phenomenological competence.

In the raw data, only three of these firms were reported at all: Exide, GNB, and Sanyo. As would be expected, Exide and GNB were both pursuing an MD 0 innovation. However, Exide was also pursuing three MD>0 innovations (Nickel-Metal Hydride, Nickel-Zinc, and Sodium Sulfur), GNB was pursuing one (Sealed, Bi-Polar Lead Acid), and Sanyo was pursuing five (Lithium-based, Nickel-Cadmium, Nickel-Metal Hydride, Nickel Hydrogen, and a Phosphoric Acid Fuel Cell). In other words, while ten of the thirteen firms which seemed intently concentrated on manufacturing Lead-Acid storage batteries were not reported at all in the public media, the three that were reported were all pursuing innovations that would possibly destroy their own core competence. This finding supplements previous discussions with the view from a narrower, more phenomenologically distinct focus; it does not contradict or replace them.

Of course, this sub-population of thirteen did not constitute the basis of a meaningful statistical test. The point of the above effort was to re-emphasize that the prevailing mental structure of what an "industry" is and where its "boundaries" are is inherently problemmatic, especially when the destruction and/or recreation of those boundaries is at issue. A morphological approach to defining what an industry really is by relating technological function, user functionality and the equation technology = competence was both logical and useful, in the sense that the above small-scale exercise yielded plain and understandable results.

Performance

Additional Tests. Next, in order to help develop an accurate interpretation of how the various technologies were being legitimated in the public media, it was prudent to estimate how, in fact, the relevant technologies were actually evolving during the period of time in question. Up to this point, it was assumed that the relevant technologies were following a pattern that could be represented as clearly as the pattern depicted in Figure 2.1, and that during the time of the study, performance and price characteristics were at points of great disparity (that lead-acid technology was very mature and that everything else was very immature). It was important to gain at least a rough understanding of the accuracy of these assumptions, before interpreting the various rates at which advantages and disadvantages were reported.

The actual characteristics of the technologies in question were estimated in three ways, the results of which are integrated in the following discussion. First, frequency tables were reorganized and tested assuming nothing about probable states of evolution, and retreating from the assumption that the media was significantly biased. Second, published technical data was consulted and third, the proceedings of the 12th annual International Electric Vehicle Symposium (held in Anaheim, California during December 5-7, 1994) were consulted.

Tables 6.1 and 6.2 present frequency data in tables that more clearly assess whether or not, according to media reports, the performance differential between competence-enhancing and competence-destroying innovations (as entire families of s-curves) actually conformed to the expectations discussed during the development of propositions. These tables differed importantly from tables previously presented and analyzed in that they considered possibilities heretofore dismissed because of their theoretical unlikelihood; for example, that competence-destroying innovations might have already been outperforming competence-enhancing innovations, and that competence-enhancing innovations might have possessed the phenomenological potential to sustain the performance superiority of the dominant design well into the long-term.

Table 6.1. Performance Superiority, MD 0 versus MD>0.

	NOWBETR=1	THENBETR=1
MD 0	72	20
MD>0	104	201

Table 6.2. Performance Inferiority, MD 0 versus MD>0.

	NOWWORS=1	THENWORS=1
MD 0	47	30
MD>0	61	12

Chi-square for Table 6.1 was 55.84 (C = .35), which rejected the null at alpha = .001. (The table essentially tested the hypothesis that competence-enhancing innovations actually performed better than competence-destroying innovations, and that competence-destroying innovations will actually perform better in the future. This was not the same as asserting that known performance advantages would be reported at dissimilar rates.) When this table was standardized, chi-square was 39.28 (C = .41), still high enough to reject the null at alpha = .001. For Table 6.2, chi-square was 9.43 (C = .24), which marginally rejected the null at alpha = .01; when this table was standardized, chi-square was 13.26 (C = .25), which rejected the null at alpha = .001. Together, these results supported the expectation that competence-enhancing innovations actually did and would continue to perform the best in the short-term, but that it was a virtual certainty that their overall performance would be surpassed in the long-term by at least one competence-destroying innovation.

On the other hand and despite the strength of these statistics, it was intuitively bothersome that there were 104 reports of an MD>0 innovation that had already achieved performance that was superior to the dominant design, and that reports of the near-term inferiority of MD 0 innovations were actually more numerous (47) than reports of their long-term inferiority (30). This implied that although the performance s-curve depicting the family of competence-enhancing innovations, when graphed alongside the performance s-curve depicting the family of competence-destroying innovations, might have looked much like Figure 2.1, graphs of s-curves at a lower level of analysis might not have differentiated MD 0 from MD>0 innovations so clearly. In fact it implied that there was probably some overlap among them.

Tables 6.3 and 6.4 present data that was suggestive of the relative positions of the families of technology s-curves defined by Phenomenological Type. The Tables showed that all reports that competence-destroying innovations were already superior to the dominant design were restricted to PTs B, D and E (Other ReDox, Hot, and Zinc-Air Batteries, respectively). Proportionately, reports of the performance superiority of Other ReDox Batteries were distributed about evenly between the two time frames; for Hot Batteries, reports were skewed towards the long-term; for Zinc-Air Batteries, they were skewed towards the short-term. Zinc-Air Batteries were never reported as having

Table 6.3. Performance Superiority, Phenomenological Type.

	NOWBETR=1	THENBETR=1
PTB	57	58
PTC	0	1
PTD	24	75
PTE	13	7
PTF	0	2
PTG	0	0
PTH	0	4
PTI	0	0

inferior performance at all, but this was not the case for Other ReDox and Hot Batteries, especially concerning the short-term. The number of times that Hot Batteries were reported as being inferior in the short-term was about the same number of times that they were reported as being superior in the short-term. Other ReDox Batteries, on the other hand, were reported many more times as being superior in the short-term than they were reported as being inferior in the short-term. Other ReDox Batteries were reported eight times as being inferior in the long-term, while innovations of other PTs were seldom reported as such.

Chi-square for Table 6.3 was 24.63 (C = .30), which rejected the null at alpha = .001; when rows containing low expected frequencies were removed, PTs B, D and E remained, and chi-square was 19.81 (C = .27), which rejected the null at alpha = .001; when this table was standardized, chi-square was 34.6 (C = .32), which rejected the null at alpha = .001. For Table 6.4, chi-square was 17.24 (C = .45), which rejected the null at alpha = .05. Subsequent tests of this table were uninterpretable because of the presence of too many low expected frequencies.

Table 6.4. Performance Inferiority, Phenomenological Type.

	NOWWORS=1	THENWORS=1
PTB	23	8
PTC	0	0
PTD.	27	1
PTE	0	0
PTF	0	0
PTG	0	0
PTH	7	0
PTI	0	2

Guided by the areas of statistical significance and the proportionality of frequencies, this pattern suggested that the performance s-curve of Zinc-Air Batteries was already above the performance s-curve of Lead-Acid Batteries and that it would probably stay above it in the future. The performance s-curve of Other ReDox Batteries, as a family, seemed to be proximate to the performance of Lead-Acid Batteries, but the performance growth of Other ReDox Batteries seemed to be faster, growing towards a higher phenomenological potential. The s-curve of Hot Batteries seemed to be not quite so proximate to (not as high as) the Lead-Acid Battery s-curve at the time, but again performance growth of Hot Batteries seemed to be faster, growing towards a phenomenological potential that was probably even higher than that of other ReDox Batteries.

Technical Data. Fortunately, contemporaneous technical data was available which helped evaluate these speculations in greater detail. Table 6.5 presents information that was consolidated from articles published by/in the Society of Automotive Engineers (Brant, 1994), the Journal of the Electrochemical Society

("Electric vehicles and batteries",1994), and Chemtech (Henrickson, DeLuca & Vissers, 1994). First, it was apparent that the theoretical specific energy (column 2) of various batteries was commonly known, at least to expert technologists in the field; these were the phenomenological upper limits of their respective performance s-curves, derived from knowledge of the properties of the respective electrochemical couples. Thus the straightforward engineering problem was to develop batteries as far up-and-along these s-curves as possible, other things held equal; or, in other words, to develop batteries with practical specific energies (column 3) that were as close as possible to their theoretical potentials. At the time, of course, devices existed at different stages of development (column 4). In order from the most marketable to the most primitive, stages of development were categorized Commercial, Prototype, Module, Stack, and Cell.

It is important to note that Table 6.5 was compiled by listing batteries in increasing order of their phenomenological potentials; it became apparent only secondarily that this order of ascendance also paralleled ascending MD and PT. Specifically, though there were some large within-PT differences in theoretical specific energy, there was no overlap between the ranges of the specific energies of any two PTs: for PTA, specific energy was 175.7 Wh/lb; for PTB, it ranged from 185.9 to 429.8; for PTD, it ranged from 548.5 to 763.6; for PTE, it was 1316.1. Of course, and as will be explained, Table 6.5 presented only a fraction of the huge number of theoretically-possible electrochemical couples. By implication, many of the others probably did not constitute sound bases for batteries because of poor phenomenological potentials, as well as being infeasible for any of a myriad of other reasons. But as it stood, the data in the table did support the overall validity of the morphological analysis developed in this dissertation in terms that mattered most. The morphological analysis developed in Appendix 1 was driven by a

Table 6.5. Composite of Battery Specifications

Phenomenological Type and Nomenclature	*Theoretical Specific Energy, Wh/kg.*	*Practical Specific Energy, Wh/kg*	*Stage of Development*
A: Lead-Acid	175.7	25-40	Commercial
B: Nickel-Metal Hydride	185.9	50-80	Module
B: Nickel-Cadmium	219.0	50-60	Commercial
B: Nickel-Iron	268.3	50-60	Prototype
B:Nickel-Zinc	342.6	n/a	n/a
B: Zinc-Bromine	429.8	80	Prototype
D: Lithium Polymer	548.5	100-200	Cell
D: Lithium Iron DiSulfide	652.0	130-200	Stack
D: Sodium-Sulfur	763.6	75-80	Prototype
D: Sodium Nickel Chloride	795.6	80-100	Prototype
E: Zinc-Air	1316.1	75-100	Prototype

technological/engineering problem that was defined by the challenge of increasing the specific energy of an electrochemical device. As it turned out, according to the best available Research and Development data, the categories derived from the morphological analysis were distinctly different not in appearance or mechanical operation (because devices within each PT were not always identical in appearance or operation), but in their theoretical specific energies. At any rate, data in column 2 corroborated the previous speculation, based mostly on the results of testing the frequencies of THENBETR and THENWORS, that the phenomenological potentials of PTs A, B, and D increased in that order, and that the potential of PTE was higher not only than PTA, but everything else as well.

Next, columns 3 and 4 together enabled an evaluation of the previous speculation, based mostly on the results of testing the frequencies of NOWBETR and NOWWORS, of how proximate the s-curves of different devices, and therefore Phenomenological Types, of competence-destroying innovations were to each other during the period of time under study. In other words, the practical specific energy of each battery indicated the actual performance of each device "NOW", while their stages of development gave a good relative indication of how truly imminent each device was to being available "NOW".

Only two batteries were noted as being in the Commercial stage of development. Technically, according to the strict logic used during the development of propositions, these were the only devices that should have their practical performance considered as existing "NOW" -- other practical specific energies should be categorized as materializing at some point in the future, or "THEN", although some non-Commercial stages of development were certainly more imminent than others. This observation was made only to highlight the importance of considering how promised (laboratory) performance might be legitimated as practical (Commercial) performance. In R&D terms, even prototypes can still be years away from commercialization, and not necessarily representative of the performance characteristics of an eventual Commercial version. A Commercial version might turn out to be superior to a laboratory version because intermediate efforts could result in further movement along an s-curve; or conversely, a Commercial version might be inferior to a laboratory version because of innumerable practical differences between a lab and the marketplace.

Anyway, one would think that after a century or so of commercial development, Lead-Acid Batteries would be far up their s-curves -- yet according to the table, there still seemed to be a great deal of untapped potential between Lead-Acid's practical and theoretical specific energies. Perhaps this reflected a lack of a truly serious challenge over its lifetime, but also it probably reflected the simple difficulty of translating scientific knowledge into technological functionality, which is the engineer's chore (Betz, 1993). At any rate, it indicated a significant opportunity for a "sailing ship phenomenon" to occur, where investments in an old technology can sometimes reap quick but short-term rewards and deceive some into believing that obsolescence is still far from imminent (Foster, 1986).

The other battery in the Commercial stage was Nickel Cadmium, which seemed to be about as far up its s-curve (by comparing practical to theoretical specific energies) as Lead-Acid was on its s-curve, despite a much shorter history. Yet its practical specific energy was superior. Considering the other, Other ReDox Batteries (PTB), two (Nickel Iron and Zinc Bromine) were in the prototype stage, and both were promising practical performance that was superior to that of Lead-Acid. The promised practical performance of Nickel-Metal Hydride was already similar to that of the other PTB innovations, despite being in an even earlier stage of development. On the whole, this corroborated the previous speculation that the performance s-curve of Other ReDox Batteries was proximate to the s-curve of the dominant design, and growing towards a higher phenomenological potential.

Concerning Hot Batteries (PTD), it was interesting that the two Sodium-based innovations, both in the prototype stage, were already promising practical performance superior to the performance of the dominant design, with most potential yet to be tapped. In other words, relative to PTB innovations, they still seemed to be near or on the bottom (flat part) of their s-curves. Of the PTD innovations, the two Lithium-based innovations were promising the best practical performance, and were already much farther towards exploiting their full potentials, yet they were in the most primitive stages of development. On the whole, this information corroborated the previous observation that the performance s-curve of Hot Batteries was not yet as proximate to the s-curve of the dominant design as was the s-curve of Other ReDox Batteries, but only because they were farther away from commercialization, not because their practical specific energies were lower.

The characteristics of Zinc-Air Batteries (PTE) seemed to be fairly clear. Their performance potential was much higher than any of the other types, and promised practical performance was superior to every other innovation except the two Lithium-based batteries. At any rate, the performance s-curve of Zinc-Air technology clearly seemed to be above that of Lead-Acid, which corroborated previous speculations.

Figure 6.1 graphically summarizes the essentials of this discussion. When viewing this figure the limitations of the available data should be appreciated; the figure is only intended to illustrate the relative positions of a few batteries and their s-curves. They are not empirically derived plots. The dashed portions crudely depict periods of time before commercialization, and phenomenological upper limits are not strict predictors of ultimately attainable practical performance. It is also important to point out that the data used was exemplary, and was not necessarily collectively representative of the activites of each player in the entire industry. The ultimate source of the information presented in Table 6.5, to be more exact, was the United States Advanced Battery Consortium (USABC), and reflected its important -- perhaps central -- subset of concerns.

The USABC was formed in 1991 as a partnership among the Department of Energy, the Electric Power Research Institute, GM, Ford, and Chrysler, and directed (non-Lead-Acid) battery Research and Development. The USABC was an important player during the period of time under study because it identified mid-and-long-term battery performance goals, conducted research itself (especially through Argonne National Labs), and helped fund specific battery development programs in individual

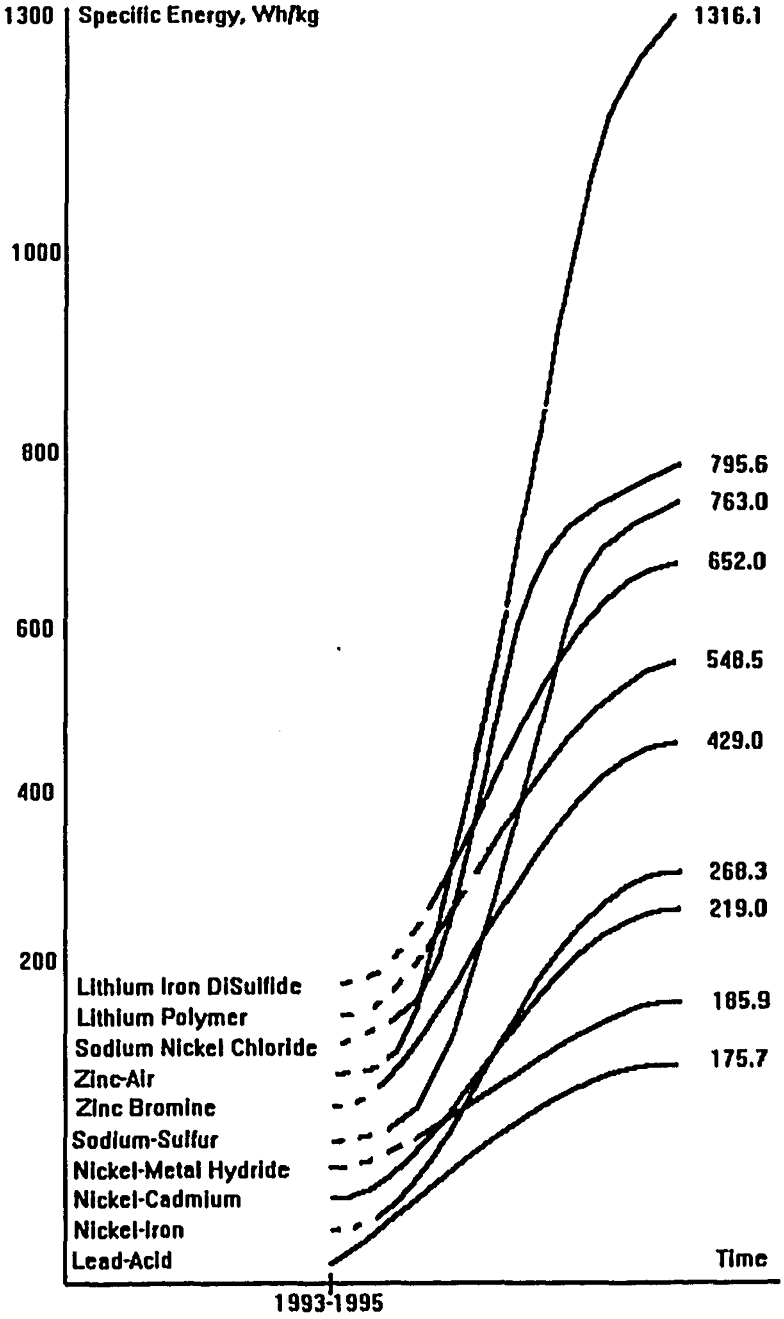

Figure 6.1. Approximate S-curves of Several Competitive Innovations.

firms such as Ovonic (Nickel-Metal Hydride), Grace, Johnson Controls, SRI, SAFT, Delco and EIC Labs (Lithium compounds), Valence Technologies (Lithium Vanadium), Silent Power (Sodium-Sulfur), and 3M and Hydro-Quebec (Lithium-Polymer) -- all PTB and PTD innovations.

In other words, the USABC probably participated in the legitimation of some battery technologies, as additionally evidenced by the conspicuous absence of some electrochemical devices in Table 6.5 -- especially Fuel Cells. However, there was no reason to suspect that the USABC had any legitimation agenda other than a broad-based advocacy of the most technically feasible battery technologies, in the larger context of the debate as to whether electric vehicles were a wise socio-technological pursuit at all. All things considered, there was absolutely no shortage of active, vocal, and very disparate organizations (including other technical consortia) taking strong positions on the overall electric vehicle issue and specific sub-issues. The USABC was only one of them, and was probably one of the more rational from a technological point of view (Sutula & Venkateswaren, 1994).

EVS-12. The 12th annual International Electric Vehicle Symposium (Dec, 1994) was contemporaneous to, and happened towards the end of, the period of time under study; perfectly positioned to facilitate a broader evaluation of EV activities than those that were being specifically championed by the USABC. The proceedings of the symposium contained several dozen technical articles specifically addressing the status of almost as many technologies, embedded in over 1200 pages of other pertinent information, all written by technologists directly involved in enacting this new industry. Because of the nature of and purposes behind symposia, trade shows, and professional conferences, it was felt that this large record was probably representative of industry-wide, advanced developments. By the same token, however, it was also felt that many of the authors were at least partly motivated by the desire to promote (hence legitimate) certain technologies, organizations, or at least the emergence of the industry in general. Therefore, though no statistical test is forthcoming in the following discussion, there was probably a "file drawer" full of uninteresting or frustrated developments elsewhere in the industry. The following discussion pertains most accurately to the aggressively innovating elite.

Even the most superficial glance at the symposium proceedings gave an impression that the electric vehicle movement was not indigenous to the U.S., but was happening globally in different ways and for different reasons. Of the more than 30 articles that addressed electrochemical technologies, most authors and co-authors represented non-U.S. organizations. Six articles were written by authors representing U.S.-based organizations (details appear in the following discussion). Eight were written by authors representing Japanese organizations, five were German, four were French, and two were British. Other authors and co-authors were apparently from Austria, Belgium, Canada, Czechoslovakia [sic], Israel, Italy, the Netherlands, and South Korea. In short, and as had become impressionistically but strongly apparent in the public media, the electric vehicle movement was conspicuously afoot throughout the U.S.-Japan-Europe triad plus a few developing countries. The 1990 California mandate to develop electric vehicles triggered a natural experiment, a relatively sound and consistent political-legal context within which a pattern depicting the struggle for technological breakthroughs, of a specific type in an identifiable industry, was observable. Yet it became clear that this natural experiment, especially since the most important underlying issue was the reconstruction of boundaries, was not clearly divorced from the larger context in which it was embedded.

Some general impressions were voiced consistently throughout the symposium proceedings, such as the following assertion made by a representative from Sonnenschein, a German battery manufacturer: "The electric vehicles business is becoming more professional. The time for 'hobby-business' is gone. Small serious production starts are at all major car manufacturers all over the world. Optimal conditions for the motive power battery and service are near-term problems [sic]" (Hanauer, 1994: 564). If this observation was correct (and there was no conflicting statement to be found), it identified, in strategic terms, where the industry (EV, or EV power source) was poised in its life cycle. It seemed to be at a nexus, a transition point of overall activity from an era of pilot or small-scale, highly individualistic and entrepreneurial, and sometimes technologically "crackpot" activities, to an era of much relatively larger scale production, more professional management, and less technologically uncertain trajectories. This transition period would indeed seem to be a junction when legitimacy had the potential for serious leverage one way or the other, not only for individual firms and technologies but for the entire new industry.

Yet the most prevailing technological certainty, ironically, was technological uncertainty. "There will be no wonder battery. It is a law of nature that the practical energy density of electrochemical batteries [as opposed to mechanical batteries, or flywheels] is approximately 1/100 of that of conventional fuels ... [but] It is possible to have the electric automobile even today. Quantum leaps are not needed to decide whether or not there is a market for the electric automobile. Continued political pressures and public acceptance are needed for the introduction of electric vehicles ... It remains that there will not be a single 'right' battery for all electric automobiles, but a number of battery systems which will complement one another" (Kruger, 1994: 202-3).

The reason for this expected technological complexity was also a humble reminder of the simplicity of the focus of this study. The only performance parameter considered was specific energy, or vehicle range. The most superior (practical or theoretical) and/or cognitively legitimate specific energy emerging at the time of this study was not necessarily destined to become part of the future dominant design because, aside from business complications, specific energy was phenomenologically interactive with other performance parameters such as specific power (acceleration), recharging time, the number of possible recharging cycles, battery "memory", and operating environment extremes. However, this reminder did not discount the validity of the views developed previously and maintained to this point. The observation only emphasized that though range was the most critical performance parameter, the one that was the most serious bottleneck in terms of consumer acceptability, no single technology was *yet* in sight that would accommodate the demands of all automobile consumers, at least in terms of the way automobiles were expected to perform generally. In strategic terms, the short-term was expected to be technologically fragmented, but this accorded with theoretical concepts like Anderson & Tushman's (1990) "period of ferment", the exciting period between a technological discontinuity and the emergence of a dominant design. Theory still suggested that in the long-term, eventually a dominant design would emerge, a design that constituted a collection of sub-technologies that together would deliver satisfactory performance to most consumers (Utterback, 1994).

In the short-term, however, much was indeed still very uncertain. At EVS-12, there was a diverse contingent of participants who felt that improvements to Lead-Acid technology would, at the very least, be the best short-term solution to even the range problem. Interestingly, this contingent had no U.S. voice; rather, articles came from Germany (Hanauer, 1994), Great Britain (Merz & Stevensen, 1994), Japan (Nakayama & Hijo, 1994; Wakasa, 1994), and South Korea (Song, Kim & Oh, 1994). Within this group, the phenomenological limitations of the Lead-Acid ReDox were well-known. The fact that so much of the technology's potential was still untapped was equally recognized, however. Hence activities aimed at incrementally improving Lead-Acid

Batteries (PTA) were intense. Whether or not these investments would prove fruitful was somewhat a matter of perspective.

It seemed certain that Lead-Acid improvements would be competitive during the crucial early years, when the new industry (EV or EV power source) as a whole was most vulnerable to failure. In theoretical terms, it seemed that Lead-Acid advocates and some others were cognizant of the "sailing ship" phenomenon (Foster, 1986) described earlier, and knew that the performance of Lead-Acid technology would flatten again after an impressive rejuvenation, only to inevitably be overtaken by a different technology. Strategically, to some this seemed to be the best way to buy time, to buy into the new industry on the ground floor, and to be agents of change. Whether or not the Lead-Acid advocates represented organizations that planned to eventually make the leap to a non-Lead-Acid technology was not clear, however, which was the substance of Proposition 1.

In other words, it is safe to say that everybody who participated in EVS-12 knew that it would be difficult -- and probably impossible -- to meet the California mandate with the permanent solution as early as 1998, but there were disagreements as to whether Lead-Acid should be pursued as a shrewd short-term, interim solution. The conundrum causing the furor was highly relevant to this study. Some experienced players, scarred by previous, failed EV movements (such as the spurts of interest that occurred during oil embargo panics) felt that the best way to ruin the present movement was to introduce marginal/mediocre technologies too early and cause irreparable, further damage to the image that already plagued electric vehicles: that they were only glorified golf carts. Others felt that at least some niche markets, such as government and industrial fleets, the military, and environmentally-conscious and wealthy trend-setters, should be pursued soon and vigorously as hands-on development programs in-and-of themselves. The resulting dilemma was how to compete in a cooperative fashion, or how to cooperate competitively -- how to legitimate one's technology, while simultaneously legitimating the whole industry full of competing technologies.

In the main, while some players advocated achieving acceptable mass-market performance through achieving a series of small discontinuities, others seemed intent on working more patiently at the R&D phase, and then making the big hit. Lead-acid advocates were plainly in favor of the former point of view, firm-specific long-term strategies notwithstanding.

So ingenuity plus politically ordained demand were pushing many incremental improvements to Lead-Aacid technology. The one version that was discontinuous in terms developed in this study, of course, was the Sealed, Bi-Polar Lead-Acid Battery (SBLA, or PTC). The history of the SBLA was relatively short and narrow. The basic technology was a product of the Cold War, having been invented by the Jet Propulsion Laboratory (Pasadena, California) as part of the Strategic Defense Initiative ("Star Wars"). Since being researched and developed in the 1980s, it seemed that SBLA technology had since been transferred (licensed) to only a few serious organizations. Harbaugh (1994) reported that the Aries Research/Exide version was promising 47 Wh/kg, a figure that squared neatly with Table 6.5. That is, during the conceptual development of PTs, B and C were designated arbitrarily; they were both MD 1, PT1 groups of innovations. Had the order been reversed (which would probably have been intuitively cleaner since it would have alphabetically adjoined both Lead-Acid PTs), Harbaugh's data would have perfectly supplemented Table 6.5, adding SBLA in a way that maintained the parallel ascendance of PT (alphabetically) and practical specific energy (numerically).

Considering Other ReDox (PTB) Batteries next, several articles concentrated on Nickel-Metal Hydride technology. U.S.-based Ovonic (Crujian et al., 1994) claimed to be producing one such battery that was delivering 70-80 Wh/kg "to the wheels" -- i.e., functioning in a commercializable vehicle. This young firm was already in the production mode, having delivered 10,000 such devices while also licensing the technology to Gates, Gold Peak, Harding, Hitachi, Matsushita, Samsung, and Varta. In other words, Ovonic was in fact delivering a level of performance that the USABC only indicated as being in the module stage. SAFT of France (Cornu, 1994) was somewhat behind Ovonic, reporting a 1994 developmental project that had the attainment of 65 Wh/kg as its goal, and a 1996 pilot project which planned to attain 80 Wh/kg. U.S.-based Electro-Energy (Reisner & Klein, 1994) reported a radical cost-saving design, but did not specify performance.

Consistent with the USABC data, SAFT (Cornu, 1994) also claimed that Nickel Cadmium technology was the only alkaline couple commercially available for automotive applications. SAFT's Nickel Cadmium battery was delivering 56 Wh/kg, and the company hoped to improve it to 65 Wh/kg by 1996. An apparent joint venture between the Furukawa Battery Company and the Tohuko Electric Power Company, both of Japan (Eguru, Yabumoto, & Onozuka, 1994) claimed to have a Nickel-Iron Battery in "secondary development" that was promising 57 Wh/kg. Yuasa-Exide of Japan (Aran et al., 1994) reported that despite the high phenomenological potential of Nickel Zinc, the technology was also fundamentally plagued by the natural tendency for the zinc to form microscopic dendrite deposits that caused electric shorts. Yet PAUG of Germany (Warthman, Ohms & Haschler, 1994) reported a laboratory Nickel-Zinc cell that was promising 65 WH/kg (which would have substituted perfectly for one "n/a" in Table 6.5), a Nickel Hydrogen prototype that was promising 55 Wh/kg, and a Nickel Cadmium pilot project delivering 45 Wh/kg (below that which was otherwise commercially available). In sum, no performance data pertaining to PTB innovations found in EVS-12 proceedings seriously contradicted the USABC data, and on the whole added detail to that part of the picture.

Considering Hot Batteries (PTD), Electricite de France (Baudry, 1994) reported a Lithium Polymer device, still in the cell/stack stage, promising 80-100 Wh/kg -- slightly lower than the USABC practical specific energy for the same technology. SAFT (Broosely & Stanewicz, 1994) reported a similar Lithium device with 105 Wh/kg, more in line with the USABC data. Most interesting was Kurematsu's description of MITI's "national project", a coordination of contributions from Japan's Central Research Institute of the Electric Power Industry, Hitachi, Japan Storage Battery, Matsushita, Nippondenso, Toshiba, and Samsung (Kurematsu, 1994). This group was collectively working on specific Lithium combinations otherwise never reported (Lithium Cobalt Oxide Ion, Lithium Nickel Oxide Ion, and Lithium Manganese Oxide). Their goal was to develop a module delivering 120 Wh/kg by 1995, and 180 Wh/kg by 2001; aggressive, but consistent with USABC data. Silent Power of Great Britain (Auxer, 1994) reported that its Sodium Sulfur Battery then operational in Ford's EV testbed (named EcoStar) was delivering 80 Wh/kg, the same as the USABC's prototype Sodium Sulfur device. Finally, the Lawrence-Berkeley Laboratory (Doeff, 1994) advocated development of "infant" Sodium Polymer technology, one that had a known phenomenological potential lower than that of all other Hot Batteries (440 Wh/kg), but was ostensibly able to achieve a greater fraction of its potential energy because of its inherently superior internal conductivity. On the whole, this portrait of PTD innovations was somewhat more diverse than that portrayed by the USABC by virtue of the inclusion of additional, exotic ReDox combinations, but performance frontiers stayed basically within or around the same range.

The picture concerning Zinc-Air Batteries (PTE) was different. Electric Fuel of Israel (Harat, Whartman, & Tiversky, 1994) boasted of being ready to start delivering 40,000 Zinc-Air Batteries to organizations in the German telecommunications and postal industries, that would immediately deliver 215 Wh/kg -- more than twice the

USABC prototype. What was even more striking was that in this and other EVS-12 data (Tomazic, 1994), range was not emphasized as being the main inherent advantage of Zinc-Air technology -- cost was. Also very illustrative, and as will be interpreted later, was that in every other EVS-12 article that contained purposive comparisons of EV batteries (Harbaugh, 1994; Kahlen, 1994; Kruger & Gareth, 1994; May, 1994; Warthman & Ohms, 1994), Zinc-Air batteries and their entire Phenomenological Type of innovation were completely overlooked.

Aluminum-Air batteries (PTG) did not appear in the EVS-12 proceedings at all, (which differed from Zinc-Air (PTE) batteries only in the additional requirement for a thermal control system), but Fuel Cells (PTs F, H, and I) did. Again, in terms of performance, Regenerative Fuel Cells (PTF) were most like ordinary batteries, in that the basic device-type was conceived to be a closed system except for the actual flow of current. Bronoel (1994) of France reported the development of "an interesting compromise between fuel cells and secondary cells" that was a Regenerative Fuel Cell, having a specific energy of 180 Wh/kg and an attainable practical potential of 300 -- if true, "so very higher than the best batteries" (424).

Naturally, because of the way they operated, the on-board specific energy of all other types (PTs H and I) of fuel cells was not so much of an obsession. Their ranges were limited to the size of the fuel tank, efficiency of the device, and the natural energy content of the fuel, as in ordinary automobiles. Thus EVS-12 articles addressing fuel cells were mostly concerned with other matters, especially cost (Barbir, 1994; Cornu et al., 1994; Howard, 1994; Swan & Arikawa, 1994). These articles were authored by representatives from Belgium, Canada, France, Italy, and the Netherlands.

In short, morphologically speaking, batteries and fuel cells belonged on the same morphological map because of their identical phenomenological underpinnings. But for practical purposes, features of fuel cells' operating characteristics made solving the range problem mechanically different. The main engineering problem (in non-regenerative fuel cells) was not increasing specific energy per se, but achieving a configuration small enough for the average automobile -- at cost.

To summarize the EVS-12 proceedings, the "present" and expected short-term performance frontiers of electrochemical EV technologies were very much in line with the more central view of the USABC. Despite the fact that most of the organizations noted in this part of the discussion were not being sponsored by the USABC, and that most of them were not U.S.-based organizations, there were only a few inconsistencies between the two patterns. A few ReDox combinations heretofore unconsidered became apparent, an Israeli firm was boasting imminently commercial Zinc-Air performance that was far superior to that predicted by the USABC, and of course Fuel Cells were not overlooked outside the USABC. But in general, this review of EVS-12 proceedings, which was data that came directly from industry participants, indicated a great deal of consistency with both the review of available, mostly USABC technical data, and the revised frequency analysis discussed before that.

Price

Additional Tests. A similar method was used to help evaluate the known cost/price characteristics of the various categories of innovations. Tables 6.6 and 6.7 present the data needed to evaluate how MD 0 innovations compared to MD>0 innovations. Chi-square for Table 6.6 was 48.26 (C= .56), rejecting the null at alpha = .001; when the table was standardized, chi-square rose to 90.02 (C = .56). Chi-square for Table 6.7 was 6.78 (C = .24), rejecting the null at alpha = .01; when the table was standardized, chi-square was 22.14, which rejected the null at alpha = .001.

On the whole, then, there seemed to be no doubt about the relative price characteristics of MD 0 and MD>0 innovations. Improvements to the dominant design were reported as the least expensive trajectory in the short-term, but by the same token

Table 6.6. Price Superiority, MD 0 versus MD>0.

	NOWCHEAP=1	THENCHEP=1
MD 0	47	11
MD>0	7	43

Table 6.7. Price Inferiority, MD 0 versus MD>0.

	NOWEXP=1	THENEXP=1
MD 0	6	4
MD>0	92	11

alternatives, on the whole, were expected to match and surpass the dominant design in the long-term. The only note of equivocation was that there were only four reports that Lead-Acid Batteries would be more expensive than alternatives in the long-term. Otherwise, Tables 6.6 and 6.7 strongly supported the expectation that the Lead-Acid, dominant design was the cheapest, short-term alternative but that this might change in the long-term.

Finally, Tables 6.8 and 6.9 were constructed to help examine the known cost/price characteristics among the various Phenomenological Types of competence-destroying innovations. Together they continued to make very clear that competence-destroying innovations were more expensive than competence-enhancing innovations in the short-term; however, reports of their potential to become as inexpensive as Lead-Acid Batteries in the long-term were not as generally. Criticisms of Common Fuel Cells were also apparent. Here, however, a lack of statistical significance in the tables disallowed any speculation about relative price characteristics among the Types. Chi-square for Table 6.8 was 2.29 (C = .21), which did not reject the null. Chi-square for

Table 6.8. Price Superiority, Phenomenological Type.

	NOWCHEAP=1	THENCHEP=1
PTB	3	17
PTC	0	0
PTD	2	15
PTE	2	5
PTF	0	0
PTG	0	0
PTH	0	4
PTI	0	0

Table 6.9 was 2.20 (C = .15), which also did not reject the null. Subsequent tests of these tables were uninterpretable.

Technical Data and EVS-12. Using the same data that was used to evaluate innovations' performance, it was more difficult to develop a coherent picture of the relative cost/price characteristics of even the most popular and important innovations. Since the USABC had set mid- and long-term goals for both performance and price, occasional attention was paid to the dollar-per-watt-hour guidelines that this agency had set forth. But this dissertation focused on performance and price independently, not in combination. To avoid confusion, therefore, technical data and EVS-12 proceedings were consulted only for information pertaining to absolute cost drivers and/or prices of deliverable EV power systems.

It was noticeable that the USABC and manufacturers articulated very few numerical estimates of the absolute cost/price characteristics of electrochemical devices. Most assertions were either coarse, verbal comparisons or highly isolated descriptions. The USABC (Table 6.5), for example, merely classified the relative costs

Table 6.9. Price Inferiority, Phenomenological Type.

	NOWEXP=1	THENEXP=1
PTB	41	6
PTC	0	0
PTD	27	5
PTE	1	0
PTF	0	0
PTG	0	0
PTH	12	0
PTI	0	0

of each technology as being "low", "moderate", and/or "high". Articles from EVS-12 proceedings also tended to make either general claims or describe cost-driving idiosyncracies in detail.

One pattern that was very clear was that Lead-Acid technology was always considered to be the most economical alternative in the short-term. The USABC labelled the cost of Lead-Acid technology as "low/moderate", as compared to other technologies in Table 6.5. Articles from the proceedings of EVS-12 agreed. The spokesperson for one Lead-Acid innovation, for example, claimed that it had the "lowest cost of any available battery today" (May, 1994: 128). Other articles about PTA innovations also made general claims about the low costs of Lead-Acid technology (Kruger, 1994; Taniguchi, 1994). Perhaps the more telling trend was that Lead-Acid was always used as the industry's cost benchmark (Merz & Stevensen, 1994; Nakayama & Hijo, 1994). In other words, non-Lead-Acid Batteries seemed to be competing with each other for superior performance, while at the same time they were competing with Lead-Acid technology for acceptable cost. The apparent reasons that Lead-Acid was the least expensive technology were highly consistent with the theoretical characteristics of a mature technology: low-cost of materials, a great deal of standardization of product design and manufacturing processes, established infrastructures for distribution and reclamation, and of very great importance to this study, in-depth knowledge of the underlying phenomenological character of the Lead-Acid ReDox.

Next, the USABC labelled the relative costs of Nickel-Metal Hydride Batteries (PTB) as "moderate", an issue that was addressed several times in the EVS-12 proceedings. Writing on behalf of Ovonic, Corrigan et al. (1994) claimed that "the inherent metallurgical and mechanical nature of the electrodes, and cheapness of materials, will ultimately lead to low-cost production" (214). Writing on behalf of Electro-Energy, Reisner & Klein (1994) asserted that their Nickel-Metal Hydride Battery, because of its construction, was "inherently cheap" (340). In other words, Nickel-Metal Hydride technology seemed to have moderate cost characteristics because of both reasonable costs of raw materials and unobstructed produciblility.

The USABC labelled the relative cost of Nickel-Cadmium (PTB) Batteries as "moderate/high". There was no evidence in the EVS-12 proceedings as to why this was so, but elsewhere it was commonly known that Cadmium, aside from being very toxic, was a relatively rare element: an inherently intractable cost barrier, if not an outright brake. Brant (1994) roughly estimated that Nickel-Cadmium Batteries were inherently about four times as expensive as Lead-Acid Batteries, even in the short-term and in small quantities, on account of this characteristic of Cadmium alone.

The USABC labelled the relative cost of Nickel-Iron Batteries (PTB) as "moderate". Again, that term was given some rough-order-of-magnitude perspective by Eguru, Yabumoto, & Onozuka (1994) who admitted that the Furakawa Company's Nickel-Iron Battery cost ten-to-twelve times as much as Lead-Acid Batteries.

The USABC did not specifically appraise Nickel-Zinc Batteries (PTB), but part of Anan's (1994) discussion of one such device did include an observation of the relatively low cost of zinc. As partial corroboration, the USABC labelled the relative cost of Zinc-Bromine (PTB) Batteries as "low/moderate".. Descriptions of Zinc-Bromine Batteries did not appear in the EVS-12 proceedings but Hackleman et al. (1992) made a similar observation of the low cost of zinc.

In contrast, Brant (1994) made an important observation about Nickel, so essential to most of the PTB innovations. He noted that the United States owned about 15% of the known Nickel deposits, and that only about 3% of that was economically extractable. In other words, despite the present price of Nickel, and regardless of any economy of scale that might be achieved at plant level, a severe diseconomy of scale existed for any vision of an EV industry that depended on vast quantities of Nickel.

In sum, information was spotty but the cost characteristics of PTB innovations did not make it clear that this was the PT of choice. Besides present absolute costs, the simple diseconomies of depending on several critical chemical elements on a paradigmatic scale seemed to present problems that transcended any firm-level competence. Within PTB, only Zinc-Bromine seemed to escape this obstacle.

The USABC data did not address SBLA Batteries (PTC), but Harbaugh (1994) asserted that though his company's version cost more than (PTA) Lead-Acid technology, it only cost about half that of other EV technologies. Based on the above estimates, however, that would still mean that SBLA technology was at least twice as expensive as the dominant design; since materials were basically the same, construction and production expenses probably accounted for this.

The USABC labelled the relative cost of Lithium Polymer (PTD) and Lithium Iron DiSulfide (PTD) Batteries as "moderate". Appraisals in the EVS-12 proceedings actually seemed more severe for Lithium technologies in general. Baudry (1994) expressed the concern that Lithium and Fluorinated materials were the most expensive ones being considered for EV applications, which was quite an indictment if the above appraisals of Nickel and Cadmium were correct. Doeff (1994) advocated the development of Sodium Polymer rather than Lithium Polymer for the same reason, despite the need to sacrifice some theoretical specific energy when making this choice.

The USABC labelled the cost of Sodium Sulfur (PTD) technology as "moderate", and Sodium Iron DiSulfide (PTD) as "moderate/high". The EVS-12 proceedings did not help clarify why, but elsewhere it was commonly known that despite the abundance and low cost of materials of Sodium-based technologies, production costs were high, coupled with the high cost of developing a meticulously-controlled and safe thermal control system. This latter characteristic was no less true for Lithium technologies (Hackleman et al., 1992).

Summarizing the cost characteristics of PTD innovations, all were inherently disadvantaged by the need for a sophisticated thermal control system. The low cost of materials mitigated this cost somewhat for Sodium-based technologies, while the opposite was true for Lithium-based technologies.

The USABC labelled the relative cost of Zinc-Air (PTE) technologies as "low/moderate". Articles in EVS-12 supported this estimate. Tomazic (1994) stated "a further increase of production costs does not influence the price of lead-acid batteries anymore. It can be seen, too, that only the value of the material of a Nickel-Cadmium Battery will be almost three times as much as the price of the zinc-flow battery including profit. [Numbers show] the very large influence of mass production on the price of the zinc-flow battery. The zinc-flow battery therefore has the greatest potential for low cost of all known EV battery systems [sic]" (403). Harats, Whartman, & Twersky (1994) agreed in principal, completing a consistently positive picture of Zinc-Air technology.

The USABC did not appraise fuel cells, but there was no doubt in EVS-12 and other data that each one was, at least in the short-term, "prohibitively expensive for a transportation application" (Swan & Arikawa, 1994: 424). Other more general literature, while also being short on specifics, was just as certain (Brant, 1994; Hackleman et al., 1994; MacKenzie, 1994). While cost obstacles abounded, the most significant seemed to be the costs of producing very sophisticated membranes and electrodes.

An honest and telling observation made by Tomazic (1994) summarized this part of the discussion best, with some added insight: "A cost comparison at this early stage of development needs the assumptions of costs as no precise data are available and as almost every designer claims for his own system, that if it is mass-produced, the battery costs the 150 Dollars which are demanded by the USABC to be an EV candidate [sic]" (405). In other words, despite some inherent diseconomies of pursuing several specific ideas, manufacturers consistently claimed eventual cost-parity of their innovations based on plant-level economies tied to mass production. Had the USABC not set cost/price guidelines, which themselves reflected the Lead-Acid baseline, it is not certain what cost predictions would have been.

Finally, a reminder is necessary. The above analysis of cost/price characteristics maintained the discipline necessary to correctly help evaluate the specific cost/price-related propositions and hypotheses that were developed for this study. The above discussion was limited to absolute costs and prices, not $/Wh, cost-effectiveness, or value. The price/performance ratio is a critical determinant of the timing of the likely substitution of one technology for another, but this ratio was dissected in a much earlier discussion in order to enable a clear and consistent evaluation of each dimension seperately.

Synthesis

The introduction to this chapter restated the overall conclusions of the previous chapter, which formed a general but clear pattern of how the performance and price advantages and disadvantages of competence-enhancing and competence-destroying innovations were being legitimated in the public media, with implications as to the incumbency of innovative firms. Subsequent discussions established a baseline, by triangulating the implications of revised frequency analysis, available technical data, and symposium proceedings, of what was actually happening in the industry. This section synthesizes all findings and offers extended interpretations.

Industry Incumbency. Although the analysis became somewhat tortuous, the first proposition was finally supported. Proposition 1 asserted that competence-enhancing innovations would be made by industry incumbents, and that competence-destroying innovations would be made by industry non-incumbents. From a purely technical standpoint, the statistical tests of the hypotheses designed to test this proposition failed. But only eight incumbents were reported in the media, and it was argued that there was almost certainly a "file drawer" of non-reported incumbent activity that was so relatively non-innovative that reversal of the interpretation of the tests was justified, if not warranted.

In other words, the pattern of actual industrial activity in this experimental setting supported Technology Cycles frameworks so strongly that the (public media) data was ironically skewed towards making misleading statistical conclusions. Of the 45 incumbents, 37 were innovating in ways that were not newsworthy, and it is safe to generally interpret non-newsworthiness as non-innovativeness. Of the eight incumbents that were reported, three were exclusively pursuing competence-enhancing innovations. Of the 80 reported non-incumbents, 68 were exclusively pursuing competence-destroying innovations. Of course, there was a grey area: 5 incumbents were pursuing competence-enhancing and competence-destroying innovations, as were 12 non-incumbents, and another 12 non-incumbents were exclusively pursuing competence-enhancing innovations. But on the whole, Technology Cycles frameworks were supported when the light of the "file drawer" problem was cast on the analysis of raw frequencies.

This conclusion remained intact even after concessions were made in the way "industry incumbency" was operationalized. The second impression, in fact, is that industry incumbency is difficult to define and operationalize. It should be recalled that one of the main arguments in a much earlier discussion was that using prevailing mental structures to map out radically different future space is inherently flawed because it is so potentially myopic (Hamel & Prahalad, 1994). Yet in the design of this study, the least problematic way to define the industry in question was to follow research precedent and use a very structured interpretation of what an industry is: Standard Industrial Classification. This was appropriate because the whole point was to assess whether or not firms deeply entrenched in a prevailing mental structure, representative of an industry's technological paradigm, would be agents of change that would eradicate that structure or at least participate in the enactment of a new one. Operationalizations momentarily aside, it was certainly true that U.S.-based firms with a primary SIC of 3691 were not agents of change, at least not broadly speaking. This was so true, however, that defining the industry as SIC 3691 became suspect as a correct operationalization. It was as if the "new" industry was already so different from the "old" industry that referring to SIC 3691 as a point of reference was moot.

In the end, however, SIC 3691 still stood as an adequate definition of the industry based not on the logic of old mental maps or prevailing industry paradigms, but for (a) phenomenological reasons and (b) the unavoidable conceptual tie-in to incumbency. For many purposes, it would no doubt be appropriate to operationalize incumbency as any or all of a firm's size, age, sales volume, embedded capital base, name recognition, etc. But the main issue in this study was the enhancement and/or destruction of competences, and analysis strongly implied that the "core" competence of this industry was expertise in the electrochemical property called reduction-oxidation (ReDox). In the light of the previous analysis, firms were only as "incumbent" as they were expert at this technology. Anything else would be proxy, or at least contaminated by other organizational characteristics not of keen interest.

On the other hand, recently it has been argued that since, in the Competence-based view of the firm, competences stand the chance of being competitively advantageous to the extent that they are inimitable, tacit, and *unobservable*, overly positivistic research is inherently limited in its potential for in-depth understanding (Godfrey & Hill, 1995). Ostensibly, therefore, it would have been very problematic, and possibly counterproductive, to have tried to determine which firms were "more" competent at the ReDox phenomenon than others. Limiting the operationalization of industry incumbency to those firms that were primarily engaged in the manufacturing of either Lead-Acid Batteries or Storage Batteries (SIC 3691) in general was imperfect, but appropriate: firms should be expected to defend most ardently that which they primarily do, not ancillary lines of business that are not their lifeblood; SIC 3691 completely contained the key intersection of core competence and the prevailing industry paradigm (dominant design); and though the core competence in SIC 3692 is also probably ReDox, there was no intersection of the dominant design and ReDox in that SIC which was not practically nonsensical for automotive applications.

In sum, the original operationalization of industry incumbency was grounded in theory and research precedent, though it was conceptually flawed by also being tied to an only-temporarily-real mental map of industry structure. After a re-evaluation from the phenomenological point of view, which was based in the more immutable structure of natural law, this operationalization was flawed because it invited all storage battery manufacturers into consideration, instead of rigorously isolating the subset of deeply incumbent Lead-Acid experts. But "deep" incumbency in a competence is tacit and unobservable, so the original operationalization was sensible, and at worst contained a Type II bias. For example, a hypothetical SIC 3691 firm, which only ever manufactured alkaline storage batteries, and which was developing an alkaline battery for electric vehicles, would have been counted as an incumbent pursuing an MD>0 innovation, statistically pressuring the incorrect conclusion that incumbents were making competence-destroying innovations. Despite this possible bias, the actual test found no statistical relationship one way or the other, and that was before consideration of the "File Drawer" problem.

It stands that 37 of the 45 incumbents, some of which might not have been truly "incumbent" in the Lead-Acid ReDox, were simply never reported at all. The U.S.-based storage battery industry was not the locus of competence-destroying innovation -- and even more poignant, it was not generally the locus of any significant amount or type of innovation at all. The majority of innovation activities of all types was spread across a number of other, sometimes very disparate industries, and the "new" industry had an obvious global character.

Unfortunately, the strength of this conclusion made moot the assertion that patterns of legitimation would be tied to patterns of incumbency. In a sense, the general lack of publicity left incumbents non-legitimated one way or the other. The bulk of the remaining discussion addresses the pattern of legitimacy among mostly non-incumbents.

Performance Advantages. Proposition 2 asserted that the short-term performance advantages of competence-enhancing innovations would be reported in the public media more frequently than the long-term performance advantages of competence-destroying innovations. Frequency analysis of H1a found that reports of the respective performance advantages of MD 0 and MD>0 innovations occurred at almost identical rates. Revised frequency analysis suggested that indeed, MD 0 innovations would perform better in the short-term, and that MD>0 innovations would performance better in the long-term. The technical literature indicated that commercially available Nickel-Cadmium Batteries were actually performing better than commercially-available Lead-Acid Batteries, but no other electrochemical devices were commercially available. On the other hand, it clearly indicated that all MD>0 innovations had the potential to deliver superior performance in the long-term. EVS-12 proceedings generally suggested, amid controversy, that Lead-Acid Batteries were the superior short-term performance choice, though it was not clear whether this preference was driven by technical or tactical concerns.

So in terms of the MD 0/MD>0 dichotomy, the respective performance advantage of neither broad classification of innovation was legitimated more frequently than the other. The public media made it opportune for the general public to be about as aware that Lead-Acid Batteries were the superior performance choice in the short-term, as it made it opportune for the general public to be aware that other technologies with superior performance potentials would appear on the market in the long-term. (To streamline subsequent discussions, media-induced opportunity for public awareness and actual public awareness will be assumed to be the same thing). This pattern of awareness was generally in agreement with what seemed to be technically true. Important exceptions were that superior Nickel-Cadmium Batteries were commercially available, and that superior Nickel-Metal Hydride and Zinc-Air Batteries were just "hitting the market". Most other innovations, despite their potentials, should not have been and apparently were not legitimated prematurely. In dichotomous terms, the general public was aware of technical "reality".

Frequency analysis of H2b found that reports of the future performance advantages of the various Phenomenological Types of competence-destroying innovations occurred at very different rates. In absolute terms, Hot Batteries fared the best (THENBETR=75), followed by Other ReDox Batteries (58), Zinc-Air Batteries (7), and Common Fuel Cells (4). Proportionately (THENBETR=1 per THENBETR=0), Hot Batteries still fared the best (49%), followed by Zinc-Air Batteries (35%), Other ReDox Batteries (24%), and Common Fuel Cells (24%). Revised frequency analysis indicated in relative terms when the inherent phenomenological potentials of the various PTs would materialize commercially (NOWBETR or THENBETR). Basically, Other ReDox, Hot, and Zinc-Air Batteries were all praised for their inherent potentials in significant numbers. More specifically, the expected commercialization of Hot Batteries was skewed towards the long-term, expected commercialization of Zinc-Air Batteries was skewed towards the short-term, and expected commercialization of Other ReDox Batteries was about evenly divided. The technical literature showed that theoretical specific energy rose numerically as PT rose alphabetically, that Lithium Batteries were farthest away from commercialization, that only Lead-Acid and Nickel-Cadmium were commercially available at the time, and that most other contenders were in the prototype stage. EVS-12 proceedings generally supported this picture, except that there were reports of then-commercially-available and superior Nickel-Metal Hydride and Zinc-Air Batteries, not just Nickel-Cadmium. Almost all descriptions of fuel cells exhibited a preoccupation with solving technical obstacles other than directly improving practical specific energy.

So looking only at the future performance advantage of competence-destroying innovations, frequencies suggested that the future of Hot Batteries was the most legitimate, followed strongly by Other ReDox Batteries, and followed weakly by Zinc-Air Batteries and Common Fuel Cells. The general public was barely aware of developments in the other PTs. Again, public awareness seemed to generally be in agreement with the technical truth, although the availability of superior Other ReDox Batteries was much more imminent than the availability of superior Hot Batteries. The availability of superior Zinc-Air and Nickel-Metal Hydride Batteries was not popularly known, but these developments were relatively late-breaking. Again, it seemed that technical accuracy and legitimacy were in general agreement, the few exceptions being at least partly attributable to the reasonable time lag that should be expected between first delivery to a customer and general public awareness.

Performance Disadvantages. Proposition 3 asserted that the long-term performance disadvantages of competence-enhancing innovations would be reported in the public media less frequently than the short-term performance disadvantages of competence-destroying innovations. Frequency analysis of H3a found no statistical significance in the rate at which MD 0 innovations were reported as being inferior in the long-term, and the rate at which MD>0 innovations were reported as being inferior in the short-term. Revised frequency analysis suggested that indeed, MD 0 innovations were very likely to actually be inferior in the long-term, and that MD>0 innovations were generally inferior performance choices in the short-term. Technical literature indicated that commercially available Lead-Acid Batteries were not actually performing as well as commercially available Nickel-Cadmium Batteries, but that none of the other promising developments were commercially available yet. Conversely, the clearly inferior phenomenological potential of Lead-Acid Batteries, combined with the commercial imminence of several alternatives, strongly suggested that Lead-Acid Batteries would fare poorly in the long-term. But again, EVS-12 proceedings indicated that there was a combined technical and tactical controversy concerning whether MD 0 or MD>0 innovations, as opposing groups, would be inferior in either or both the short and long terms.

So in terms of the MD 0/MD>0 dichotomy, the performance disadvantage of neither broad classification of innovation was being legitimated (the term "de-legitimated" will be used henceforth for greater clarity) more frequently than the other. General public awareness did not disfavor the dominant design for its probable long-term performance inferiority more or less than it disfavored potential replacements for their short-term performance limitations. This pattern was generally consistent with the technical truth, with three important exceptions: the actual commercial availability of superior Nickel-Cadmium, Nickel-Metal Hydride, and Zinc-Air Batteries.

Frequency analysis of H3b found that reports of the short-term performance inferiority of the various Phenomenological Types of competence-destroying innovations occurred at very different rates. In absolute terms, Hot Batteries fared the worst (NOWWORSE=27), followed by Other ReDox Batteries (23) and Common Fuel Cells (7). Proportionately (NOWWORSE=1 per NOWWORSE=0), Common Fuel Cells fared the worst (44%), followed by Hot Batteries (13%), and Other ReDox Batteries (8%). Revised frequency analysis suggested in very rough terms how long the various PTs would remain inferior, if they were inferior (NOWWORSE -v.- THENWORS). The test was statistically uninterpretable, but a face-value interpretation suggested that Other ReDox Batteries would not remain inferior as long as Hot Batteries would remain inferior. The technical literature added important detail to this picture by suggesting that though Hot Batteries inherently had the potential to not remain inferior for a longer period of time than Other ReDox Batteries, the latter were generally in more advanced stages of development; hence commercial inferiority of Other ReDox Batteries would probably end sooner. Again, Nickel-Cadmium Batteries already were no longer inferior. EVS-12 proceedings verified this point, and also evidenced the commercial availability of Nickel-Metal Hydride and Zinc-Air Batteries that were not inferior to Lead-Acid Batteries.

So looking only at the de-legitimation of the short-term performance disadvantage of competence-destroying innovations, the general public was aware that Hot Batteries and Common Fuel Cells would not compete well with Lead-Acid Batteries in the short-term, and was slightly less aware that Other ReDox Batteries would not compete well with Lead-Acid Batteries in the short-term. Aside from the above-noted exceptions, revised frequency analysis, technical literature, and EVS-12 proceedings all suggested that public awareness was generally in accordance with the technical truth, when stages of development were considered along with phenomenological potentials.

Performance Summary and Interpretation. In sum, though it was laborious and sometimes redundant, it proved fruitful to explicate reports of performance disadvantages as well as performance advantages. Doing so surfaced symmetries and asymmetries that would not have been apparent, and one-sided interpretations could otherwise have been a result. In absolute terms, it was much more common to observe a performance legitimation variable (NOWBETR or THENBETR) than it was to observe a de-legitimation variable (NOWWORSE or THENWORS). This asymmetry was intuitively appealing because performance superiority would seem to be the more direct and newsworthy claim. Yet comparing the results of testing H2a with H3a, there was a great deal of symmetry between the interpretations. The general public was very much aware of the relative performance advantages and disadvantages of competence-enhancing and competence-destroying innovations (as a dichotomy). This awareness was an accurate reflection of the technical truth, and neither competence-enhancing nor competence-destroying innovators were enjoying or suffering from generally inaccurate media representation.

Looking more closely at competence-destroying innovations (H2b and H3b), symmetry was again evident. Hot Batteries got the most publicity, but this was true of reports of relative advantages and disadvantages. Other ReDox Batteries got the second-most publicity, again in reports of advantages and disadvantages. One reasonable explanation was that as a Phenomenological Type, Hot Batteries had a higher phenomenological potential than Other ReDox Batteries, which made them more exciting and newsworthy in that sense; but they were also somewhat farther away from commercialization, an equally newsworthy counterpoint.

A simpler explanation, of course, was that there were a few more Hot Batteries than Other ReDox Batteries under development, so there was more to report -- an observation that certainly explained much of the reason that other PTs were not reported in significant numbers. Only a few firms were pursuing SBLA Batteries (PTC), Zinc-Air Batteries (PTE), and Aluminum-Air Batteries (PTG).

It was not difficult to speculate as to why Zinc-Air, such an obviously superior candidate for EV propulsion, received so little notoriety. As implied, only a few organizations were involved in their development, so only so much publicity should reasonably be expected. But also, it is interesting to speculate that in the race for performance supremacy, it might have been much more natural and easy for technologists, journalists, etc., to compare and contrast technologies that were competing for leadership within the same paradigmatic vision, to the detriment of fringe technologies that would define different visions.

To explain, most batteries being developed for EVs ascribed to the vision that EVs would be fundamentally different than gasoline-engine automobiles -- but all in the same way. When powered by most examples of batteries, EVs would have the operating and maintenance characteristics of big electronic appliances, not cars. They would require home recharging, for example, so range would be limited not only because of the state of the art of electrochemistry, but because of the absence of a private or public infrastructure of away-from-home "refueling" opportunities.

Until the emergence of a dominant design, technological choices within this vision would be mutually exclusive. Here, a portion of the neophyte EV industry was struggling to survive by retrofitting existing vehicle platforms with the best available electrochemical devices, but virtually all visionaries agreed that for the industry to ever really have a chance at achieving significant market volumes, "clean-sheet" vehicle designs (designs that started from scratch, without reliance on off-the-shelf componentry) were a collective must. However, clean-sheet electric vehicles were, and were expected to continue to be, very sophisticated, tightly integrated and in the short-term, *unique* systems. Such high levels of systems engineering meant that for the most part, battery interchangability was as least as far off as the establishment of a dominant design. Such was the general gravity of the issue concerning electrochemical devices. Whole vehicles were designed around each individual choice, and the competition among electrochemical devices was quite possibly also the competition for which vehicle design would eventually dominate the revised automotive paradigm.

But Zinc-Air and Aluminum-Air Batteries, despite being more morphologically distant from, and in that sense more exotic than, rechargeable batteries, would help create an EV paradigm that would not be very much different from the present automotive paradigm. Because PTE and PTG batteries would require replacement of reactant materials, not recharging, and because it was technologically easy to design such devices with rapid change-out features, PTE and PTG technology was amenable to the fairly rapid establishment of a "filling station" infrastructure, rather than a "plug-in" infrastructure that necessarily would be an elaborate extension of prevailing power grids. The most technologically discontinuous battery innovations, in other words, ironically would be least disruptive to the general psychology of how cars "are supposed to work" in terms of supporting existing lifestyles. The technologies which supported this paradigm were two of the least legitimated, despite the apparent technological superiority of one.

The relative lack of publicity concerning fuel cells was also noticeable. The construction and architecture of Common and Hot Fuel Cells inherently enabled ranges that were superior to all types of batteries, and EVS-12 proceedings reported one type of Non-Regenerative Fuel Cell that had a very high specific energy. Also, like Zinc-Air and Aluminum-Air Batteries, fuel cell-powered electric vehicles would operate much like ordinary gasoline automobiles. An infrastructure of filling stations -- of some sort of hydrogen-based liquid or gaseous fuel, most likely -- would need to be created, but enslavement to an electric power grid would not be necessary. However, in addition to the above speculations about why Zinc-Air and Aluminum-Air Batteries lacked publicity, the general rarity of reports of Fuel Cell performance (advantages and/or disadvantages) was also explained by the presence of other important, imposing and to some, intractable technical obstacles. But all electrochemical devices faced some technical obstacles other than simply increasing practical specific energy, and the fact remains that the general public was relatively unaware of the performance characteristics of fuel cells.

In sum, the cognitive legitimacy of the relative performance advantages and disadvantages was relatively high and symmetrical for Lead-Acid, Other ReDox, and Hot Batteries. The cognitive legitimacy of SBLA and Aluminum-Air Batteries, and Non-Regenerative and Hot Fuel Cells, was always too low to be statistically interpretable. The cognitive legitimacy of Zinc-Air and Common Fuel Cells was statistically marginal, and interpretations were idiosyncratic. Overall, the pattern of cognitive legitimacy was very similar to the apparent pattern of actual industry activity. If there was a media war, a set of campaigns designed to inaccurately represent the performance advantages and disadvantages of various electrochemical innovations being developed for electric vehicles, they were mostly ineffectual. The general absence of incumbents, of course, rendered this conclusion unsurprising.

Price Advantages Proposition 4 asserted that the short-term price advantages of competence-enhancing innovations would be presented in the public media more frequently than the long-term price advantages of competence-destroying innovations. Frequency analysis of H4a found that reports of the relative price advantages of MD 0 and MD>0 innovations occurred at very different rates. There was much more praise that Lead-Acid Batteries were inexpensive, than there was praise that alternatives would become as inexpensive as Lead-Acid Batteries. Revised frequency analysis suggested that indeed, Lead-Acid batteries were the least inexpensive, but that alternatives would become cost/price-competitive in the future. The technical data characterized the inherent costs of Lead-Acid, Zinc Bromine and Zinc-Air Batteries as "low/moderate"' but of these, only Lead-Acid Batteries were readily available commercially. EVS-12 proceedings indicated that Zinc-Air Batteries were just becoming commercially available, but not yet at a competitive cost/price. Sundry other observations supported Lead-Acid's short-term price superiority. Most comments about the future cost/price characteristics of its alternatives were in the form of allusions to firm-specific cost management skills, the inevitability of scale economies, and cost-effectiveness (good value despite high price). Lead-Acid Batteries were unquestionably the cost/price benchmark.

So in terms of the MD 0/MD>0 dichotomy, the short-term cost/price advantage of Lead-Acid Batteries was much more legitimate than the long-term cost/price advantage of its alternatives. This pattern of awareness was in general agreement with what seemed to be technically true. As theory predicted, Lead-Acid Batteries were by far the superior short-term choice in terms of cost/price, and the general public was aware of this. The general public was not nearly as aware (as industry players were confident) that alternatives to Lead-Acid Batteries would become cost/price competitive in the future. Theory agreed with the industry insiders, but at such an early stage of industry development confidence was based on entrepreneurial optimism and faith that technological history would once again repeat itself.

The general level of publicity concerning the price advantage of competence-destroying innovations was low (see above discussion), and frequency analysis of H4b found that reports of the long-term price advantage of the various Phenomenological Types of competence-destroying innovations occurred at very similar rates, on a statistical basis. In absolute terms, Other ReDox Batteries fared the best (THENCHEP=17), followed by Hot Batteries (15), and more distantly by Zinc-Air Batteries (5) and Common Fuel Cells (4). Proportionately, however (THENCHEP=1 per THENCHEP=0), results were virtually reversed; Common Fuel Cells fared the best (24%), followed by Zinc-Air Batteries (23%), Other ReDox Batteries (7%) and Hot Batteries (6%). Revised frequency analysis strongly supported that if competence-destroying innovations would indeed be cost/price competitive, it would be in the long-term (NOWCHEAP -.v.- THENCHEP), but the pattern among the PTs was statistically uninterpretable. The technical literature and EVS-12 proceedings were consistent with each other in suggesting that general cost/price characteristics of various specific devices would be driven by factors both within and beyond the control of firm-level management. Categorically, only Zinc-Air Batteries (PTE) seemed to be in a truly advantageous position because of the low cost and ready availability of materials, and because of production economies that had already been worked out in the short-term. SBLA Batteries (PTC) were convincingly situated as next-to-least expensive, because of spillover competence in the Lead-Acid ReDox and the ability to take advantage of existing supply and reclamation infrastructures. No other PT was categorically indicated as being inherently inexpensive, though Zinc-Bromine technology by itself was inherently inexpensive because of the low cost of materials.

So looking only at the long-term price advantage of competence-destroying innovations, frequencies indicated that Other ReDox and Hot Batteries were the most legitimate (awareness was about evenly divided between these two PTs). Yet categorically, actual cost-reducing advantages of these PTs were not very convincing. (In fact, each of these categories faced very severe cost obstacles, but disadvantages are the focus of H5b). Relatively speaking, for example, cost-reducing opportunities in SBLA (PTC) seemed unobstructed, yet the public media reported this characteristic not once. Categorically, cost-reducing advantages of Zinc-Air Batteries (PTE) were also distinct, but on the other hand this observation is idiosyncratic, as there was only one example (Zinc-Air) in this PT (E).

Nevertheless, in stark contrast to the consistencies which appeared in the evaluation of H2b and H3b, there seemed to be an inconsistency between the pattern of PTs that were publicly "known" to become cost/price-competitive in the future, and the pattern of PTs that technically seemed to be more inherently advantaged at achieving cost/price competitiveness. However, the fruitfulness of juxtaposing the results of H2b and H3b suggested that interpreting the results of H4b beyond this observation should be postponed until H5b could be assessed.

Price Disadvantages. Proposition 5 asserted that the long-term price disadvantages of competence-enhancing innovations would be reported in the public media less frequently than the short-term price disadvantages of competence-destroying innovations. Frequency analysis of H5a found that reports of respective price disadvantages occurred at very different rates. There was much more criticism that MD>0 innovations were expensive in the short-term, than there was criticism that MD 0 innovations would not maintain price superiority in the long-term. Revised frequency analysis suggested that indeed, MD>0 innovations were expensive at the time, and with a bit of equivocation, that MD 0 innovations would probably be about as expensive as its alternatives in the future. Technical data indicated that the only MD>0 innovation that was commercially available in the short-term (Nickel-Cadmium) was much more expensive than Lead-Acid Batteries.

So in terms of the MD 0/MD>0 dichotomy, competence-destroying innovations were much more severely de-legitimated than competence-enhancing innovations for their relative cost/price disadvantage. The general public was much more aware that MD>0 innovations were expensive, that it was aware that MD 0 innovations would not maintain their cost/price superiority in the long-term. In dichotomous terms, however, it would be an oversimplification to assess this pattern of awareness as being either in agreement with the technical truth, or not. There was much variation within the MD>0 side of the dichotomy.

Frequency analysis of H5b indicated which PTs were particularly troubled by cost/price obstacles. In absolute terms, Other ReDox Batteries fared the worst (NOWEXP=41), followed by Hot Batteries (27), Common Fuel Cells (12), and Zinc-Air Batteries (1). Proportionately, (NOWEXP=1 per NOWEXP=0), Common Fuel Cells were devastated (133%), followed much less severely by Other ReDox Batteries (16%), Hot Batteries (13%), and Zinc-Air Batteries (4%). Revised frequency analysis suggested the likelihood that cost obstacles might be overcome (NOWEXP -v.- THENEXP). Though the statistical test was uninterpretable, Common Fuel Cells and Zinc-Air Batteries were never reported as being expensive in the long-term, while Other ReDox Batteries (THENEXP=6) and Hot Batteries (THENEXP=5) were. Technical data did not clearly indicate categorically why there were different cost obstacles, but EVS-12 proceedings and other literature did. On the whole, though they were categorically simpler than Hot Batteries, most Other ReDox Batteries were faced with severe cost-of-materials obstacles, some of which only got worse with increasing scale. Several Hot Batteries were also faced with cost-of-materials obstacles, and they all were faced with the obstacle of developing sophisticated and safe thermal control systems. This latter obstacle, of course, also applied categorically to Aluminum-Air Batteries (PTG) and Hot Fuel Cells (PTI). All fuel cells were faced with extremely severe cost obstacles of materials, producibility, and for practical purposes, miniaturization. Categorically, only SBLA and Zinc-Air batteries did not face any glaring short-term cost obstacles other than the obvious -- scale economies would take time (volume, really) to establish.

So among the Phenomenological Types of competence-destroying innovations, the general public was more aware of the cost/price obstacles facing the development of Other ReDox Batteries and Hot Batteries than it was aware of the cost/price obstacles facing the development of other PTs. Specific reasons varied. On a proportional basis, the general public was much, much more aware of the short-term cost/price problems concerning Common Fuel Cells as it was aware of similar problems concerning anything else.

Price Summary and Interpretation. It again proved fruitful to explicate reports of price disadvantages as well as price advantages. In absolute terms, it was much more common to observe a cost/price de-legitimation variable (NOWEXP or THENEXP) than it was to observe a cost/price legitimation variable (NOWCHEAP or THENCHEP). This asymmetry was not intuitively appealing as much as it made simple technical sense. After all, Lead-Acid technology had been developing decades -- sometimes a century -- longer than most other technologies, and its cost/price characteristics were about as low as could ever be expected for any technology. The race, realistically, was to get as close to Lead-Acid's cost/price as possible; becoming cheaper in absolute terms was never considered to be a realistic goal.

Comparing the results of testing H4a and H5a, the asymmetry was striking. The general public was much more aware of all short-term cost/price realities than it was aware of long-term probabilities and/or possibilities. The general public was very aware that Lead-Acid Batteries were the least expensive alternative to powering electric vehicles, and also was very aware that collectively, alternatives were very much more expensive. Relatively speaking, the public was unaware that alternatives would probably become reasonably priced in the long-term. As assessed by the pattern of media reports, the general public was not aware of what theory, other technology histories, and industry insiders predicted would happen concerning the cost/price characteristics of alternatives to the present dominant design.

Comparing the results of testing H4b and H5b, the picture became more complex and intriguing. First, results were generally symmetrical. The general public was aware the Other ReDox and Hot Batteries were expensive <u>and</u> that they would become cost/price competitive in the future compared to most other PTs. Reports of the cost/price characteristics of Common Fuel Cells were very asymmetrically disfavorable, focusing on their short-term cost/price exorbitance. All other PTs got very little publicity one way or the other. On the surface this seemed placid. But considering technical data and symposium information, the symmetries became disconcerting. PTs that were inherently economical received very little publicity. The PTs that garnered the most publicity were characterized by severe cost/price obstacles: here, awareness of short-term disadvantages seemed to be driven by the ability to easily observe actual problems, while awareness of long-term advantages seemed to be driven by the willingness to hear experienced optimism. Again, the overall cognitive legitimacy of Other ReDox and Hot Batteries, and even Common Fuel Cells, is easy to accept because there were many more examples of devices within these PTs than others. Several other PTs contained only one definitive example, so publicity in those PTs should be expected to be proportionately less.

In sum, the cognitive legitimacy of relative price advantages and disadvantages was not generally as high as the cognitive legitimacy of relative performance advantages and disadvantages. That is, judging by the absolute frequencies of all eight measures of legitimacy, performance was "argued" more often in the media in general. This supports theory, which asserted that though the substitution of one technology for another is a function of comparable price/performance ratios, superior performance is the more influential variable (Foster, 1986). It makes sense that since technological leadership primarily means performance leadership, a struggle for legitimacy would tend to that dimension more often. Focusing only on price advantages and disadvantages, however, cognitive legitimacy was skewed towards short-term concerns, which heavily favored the dominant design. Lead-Acid, Other ReDox, and Hot Batteries altogether garnered most of the publicity (pro and con), though the two latter PTs accounted for a clear plurality of all distinct and feasible competence-destroying innovations.

However, this is no small point; observing the population of each PT is not merely to, in a sense, roughly control for different sample sizes in each PT. In an earlier discussion, it was pointed out that some subtle phenomenological differences carried very, very dramatic paradigmatic implications. SBLA, Other ReDox, and Hot Batteries, as well as Regenerative Fuel Cells, were all part of a similar automotive paradigm from a total lifestyle point of view. They all were basically rechargeable batteries that needed to be plugged in and recharged to be "refueled". Thus they were tied to power grids and in effect would transform the automobile industry, or at least create the EV industry, into being an extension of the electric utility industry. Zinc-Air and Aluminum-Air Batteries, as well as Common and Hot Fuel Cells, were paradigmatically different. They all needed replacement of depletable fuels, and though electric, only needed access to an infrastructure of "filling stations". Replacing Zinc or Aluminum cassettes in batteries in effect would make this sub-paradigm a direct extension of mineral extraction industries, and refueling a fuel-cell-driven vehicle with a hydrogen-based liquid or gaseous fuel would also be a sub-paradigm directly tied to natural resources extraction.

The point is that if any industry was "winning" the technological and institutional struggle for the initial configuration of the upcoming (but not inevitable) electric vehicle paradigm, it was the electric utility industry. Rechargeable Lead-Acid Batteries were the strongest candidate in the short-term, and were also one of the strongest candidates for a possible period of transition. Rechargeable Other ReDox and Hot Batteries, en masse, captured the majority of attention where competence-destroying innovations were concerned -- they might destroy the competences of Lead-Acid Battery manufacturers and possibly Big Auto in the process, but PTA, PTB, and PTD would collectively only enhance the revenues of the electric utility industry. The amount of publicity -- pro and con -- generated by industrial activities in pursuit of these three Phenomenological Types of innovations were making highly legitimate the basic idea that electric vehicles would be "battery"-powered vehicles very similar in operation to portable razors, laptop computers, camcorders, and the like. Details presented in this study were by no means exhaustive, and the amount of publicity on the matter made obvious that the whole issue was enormously complex. But if cognitive legitimacy was truly an indication of a strong head start, it was not certain that elements of the emerging paradigm represented the most superior technological trajectory from either a performance or cost/price point of view.

Since this part of the discussion is concluding, it is appropriate to add perspective to the very strict focus maintained in this study. Again, the technological problem was very strictly defined, as being the challenge of improving the specific energy of an electrochemical device for all-electric vehicles, and the specific functional problem was defined as improving the range of all-electric vehicles. One of the reasons that this focus was chosen, aside from its amenability to a relatively simple and understandable morphological analysis, was that the goings-on at higher levels of analysis were technologically and institutionally obvious.

Where technologies were concerned, it was necessary to exclude hybrid electric vehicles from consideration because, despite their capacity to vastly improve (decrease) automobile emissions, they could never completely eliminate them. As the name implies, hybrid EVs are vehicles with combined internal combustion and electrical/electrochemical features, and any internal combustion of any oil-based fuel whatsoever is incapable of being completely non-polluting. This is not to say that hybrid vehicles are bad ideas -- but they are technically non-compliant with the California legislation used as the basis for defining the present experimental context.

On the other hand, flywheel, ultracapacitor, and solar/photovoltaic technologies were compliant with the California legislation, but were not considered in this study because their morphological distinctions were one-and-the-same with their places in resolving the range problem. First, ultracapacitors provide short surges of great amounts of power, which affect range only indirectly because they ameliorate the trade-off between acceleration and range. Second, no reasonable technologist expected solar and photovoltaic technologies to be directly competitive with batteries and fuel cells as central technologies in the overall solution to EV range at any time in the foreseeable future, though they also held potential as range extenders.

But flywheels, or mechanical batteries, had very, very much more phenomenological potential than any electrochemical device, but likewise faced technological obstacles that also made them very, very much more expensive than electrochemical choices. A flywheel can be thought of as the spinning component of a gyroscope. There is an enormous amount of kinetic energy that can be stored in such a component, that can be reconverted into electricity in an electric vehicle. In terms developed for this study, flywheels were potentially adequate solutions to the EV range problem -- but their dependence on kinetic rather than electrochemical phenomena placed them on an entirely different morphological map, the implications of which were explained during the theoretical development of this dissertation. In short, choices among electrochemically-based options defined discontinuities on one map, or at one level of analysis, while making a leap from electrochemical to kinetic phenomena would be to make a discontinuity so large that it would jump from one map, or level of analysis, to another. The technological difference between these two maps was so distinct that performance and cost characteristics were incontrovertible.

Where institutions were concerned, the point is much the same. This study chose a focus that was below a level of analysis where the contrasts were patently obvious, and not worth verifying through laborious and time-consuming research. As implied above, the major automobile manufacturers naturally were ambivalent about the advent of electric vehicles, and the petrochemical industry naturally was adamantly opposed, and these general patterns of advocacy were obvious in the public media. As well, electric vehicles naturally were favored in principle by environmentalists, suppliers of electronic and electrical equipment, and suppliers of electric power. In fact the electric utility industry probably had the most to gain, because by virtue of high daytime demands for electric power, the industry had enormous excess nighttime capacity -- exactly the time frame when (hopefully millions and millions of) EV batteries would need hours and hours of recharging. So in the media the "pro" EV constituencies were just as obviously promoting the whole movement as the "anti" EV constituencies were attacking it.

Jobs were an important issue as well. Paradigmatic change from the internal combustion paradigm to any electric paradigm would certainly trigger some job migration, and antagonists were clearly defined both geographically (e.g., Michigan v. California) and institutionally (e.g., the United Auto Workers v. thousands of displaced defense industry engineers).

In other words, the results of this study were doubtlessly associated with the non-obvious, relatively low level of analysis chosen and maintained. The advent of the EV was assumed, in terms defined by California law, and fortunately, this scenario did not change during the period of time under study. For practical purposes, the contest mandated by law was for the best electrochemical device. On a grander scale, the outcome of the drama was not certain, but the stakes were plain, and the battle was not a subtle one.

Summary

Gaining an understanding of actual industry activity en route to interpreting patterns of legitimacy was a prudent decision. Otherwise, interpretations of the very elegant overall pattern of public media reports would have been unfounded and very possibly incorrect.

The U.S.- based storage battery industry was not the main impetus behind developing electrochemical devices for electric vehicles. In fact, the U.S.-based storage battery industry was not even the impetus behind developing storage batteries for electric vehicles. Rather, the impetus was dispersed both geographically and industrially. Innovative activity was being driven by activities dispersed among a complex web of firms, coalitions, industries, individual entrepreneurs, and private and public institutions advocating a wide variety of concerns. Strictly at the level of analysis maintained in this study, and strictly from the technological point of view, the new EV power source industry -- wherever were its boundaries -- seemed to be relatively fresh and unburdened from the impediments of powerful "incumbents".

Nevertheless, there were distinct patterns of activity in the cognitive legitimation, or legitimacy, of various technological choices. From the broadest perspective, performance was the issue argued more often. Here, technology s-curves could be estimated that suggested that technologies were evolving very much in agreement with theory. The only real surprise was that a few competence-destroying innovations were encroaching upon the dominant design much sooner than expected. Then, as measured in ways specifically developed for this study, it was found that the general public held a balanced and accurate understanding of both the actual short-term and relatively certain, long-term performance trends. Naturally there were a few exceptions such as the occasional under-appreciation of relatively unusual innovations germinating in other countries, and there was some qualitative evidence of a time lag between an event like product commercialization and broad-based public awareness of its availability. But on the whole the general public accurately understood actual industry activity which was progressing very much like theory would predict. It is oversimplified but correct to say that in terms of performance, the pattern of cognitive legitimacy agreed with the pattern of technologically legitimate pursuits.

In very distinct contrast, the general public was acutely aware of short-term cost/price characteristics, which very much favored the dominant design, and was relatively unaware that the future cost/price characteristics of competence-destroying innovations looked promising to many insiders. Competence-destroying innovations faced an important public image problem because of short-term costs and prices; yet many industry players were just as confident that long-term cost/price obstacles would be conquered, as they were confident that long-term performance potentials would be achieved. Apparently, in terms of cost and price, the dominant design was more legitimate because short-term problems faced by makers of its alternatives were severe enough to cloud expectations of their futures.

CHAPTER 7: IMPLICATIONS AND CONCLUSION

In 1990 the California legislature fired a starting gun which challenged all comers to develop marketable, non-polluting automobiles by 1998. From early 1993 to early 1995, political resolve had not changed and innovators had made much progress towards developing devices that would power all-electric vehicles; most were electrochemical. For the most part, the U.S.-based storage battery industry was not participating in this race in newsworthy ways, but at least 100 firms from other industries and nations were dedicating serious amounts of resources towards getting into the new industry early. Within that group of innovating firms, most of the competition was aimed at developing storage batteries that were capable of producing greater specific energy (hence vehicle range) than that which was then available from state-of-the-art Lead-Acid Batteries. Some firms were seeking to merely improve Lead-Acid Batteries, while others were developing storage batteries with electrochemical couples made of materials other than lead, and some of these required sophisticated thermal management systems just to keep key materials molten. Each had fairly clear short-term performance characteristics and long-term performance potentials. Generally speaking, performance and commercial availability were inversely related.

However, other types of innovations were under development as well. One unconventional type of battery departed from the normal characteristics of storage batteries in that it required the periodic replacement of depleted reactant materials, as opposed to recharging. This Zinc-Air battery showed better short-term performance and promised better long-term performance than any other battery under development. Different types of fuel cells were also under development: all but one type also required refueling rather than recharging, and by storing fuel outside the device itself, had inherently greater vehicle range potentials than most conventional storage batteries.

A coarse but structured analysis of the way the public media represented these industrial developments indicated that the general public was much more aware of the pros and cons of developments in the competition among conventional storage batteries, than it was aware of the pros and cons in the wider competition which also involving less conventional innovations. If total public awareness was a simple kind of legitimacy that could be ascribed to innovations, and if the more legitimate innovations were more likely than the less legitimate innovations to eventually replace the dominant design, then the emerging EV automotive paradigm was one that was probably going to be powered by rechargeable storage batteries. Though other, more discontinuous or competence-destroying innovations showed greater performance potentials, with (from one point of view) no greater eventual disruption of lifestyles and industries, "legitimate" EVs were the kind that consumers would have to plug in periodically like familiar, rechargeable electric accessories.

Performance was generally the main concern, but the price of all electrochemical devices was sure to be very high in the short-term, especially for fuel cells. EVs based on Lead-Acid technology would be expensive too, but about a century-long head start positioned them as being the least expensive in the short term. Many industry players were confident that just as the performance of EVs would continuously improve, prices would also fall, to points where non-Lead-Acid alternatives would be price-competitive in the long-term. However, the general public did not share this confidence in the same way that it shared confidence in performance improvement. Storage batteries were the "legitimate" performance choice and within that realm of technologies, Lead-Acid was clearly the "legitimate" choice based on price.

This chapter explores the theoretical, practical, and research implications of these findings, organized in the same manner as was the literature review. Conclusions are then presented.

Strategic Management

It was argued in earlier chapters that adopting the underdeveloped but accommodating Resource/Competence-based view of strategy was an appropriate way to focus on technology and technological change in Strategic Management research. The implications of this study support this argument, but identify limitations as well.

When wrestling with the ambiguities and imperfections of operationalizing industry incumbency, it was argued that when the enhancement and/or destruction of competences is at issue, then the most meaningful dimension of incumbency is deep expertise in the technologies that are at the heart of the matter. In this study, for example, the core technology (and thus core competence) was expertise in the reduction-oxidation phenomenon; Lead-Acid was the particular ReDox of the dominant design, and success principally hinged on firms' abilities to extract practical specific energy from the phenomenological potentials contained in various ReDox pairs, or electrochemical couples.

But theoretically, a core technology or core competence has the potential to be competitively advantageous to the extent that it is difficult for outsiders to understand, imitate, or at least observe (Godfrey & Hill, 1995). To an academic researcher this is a severe metaphysical conundrum, because researchers are outsiders, too. Specifically, in order for research to yield conclusive results, positivism demands empirical observation. Strict adherence to a positivistic research paradigm implies that researchers interested in studying core competences are attempting to observe and measure firm-level expertise that is deeply embedded, tacit, and at least at some point, unobservable. Thus this study did not attempt to operationalize industry incumbency beyond identification of products which represented specific combinations of competences (stage of development notwithstanding). In other words, in the technology-is-competence view, products do not contain technologies as much as they provide evidence of them.

If technology is competence (Betz, 1993), and if knowledge is a main component of competence, then by implication technological change involves learning (Clarke & Wheelright, 1993; Cooke & Morgan, 1994), and discontinuous technological change involves either re-learning or new learning (Cohen & Levinthal, 1995; Hamel, Doz & Prahalad, 1995). Learning can be serendipitous, of course, and the variation-selection-retention (ecological) model of evolutionary technological change has even been proposed as being fundamental to an intra-organizational strategy of innovation and environmental adaptation (Burgelman, 1983). But in the present scenario learning was mostly a matter of choice. The future technological environment was basically mandated by law, and serendipity would surely be an unreliable firm-level strategy aimed at capitalizing on the California mandates. Clear (or at least resolute) technological goals and deadlines restricted and/or distorted underlying ecological mechanisms so severely that attempting interpretations strictly in these terms would be to dismiss the obvious.

In this scenario, the more distinct mechanism at work was choice. The findings of this study clearly implied that some technological trajectories are consciously intended trajectories of learning, and some very non-accidental, non-probabilistic technological trajectories can be crafted to knowingly and willingly cause the de-maturation, rejuvenation, or complete destruction of entire industries (Abernathy & Clarke, 1988). Furthermore, non-market forces for technological change are likely to become more common in the future (Porter, 1990; Carlsson, 1994; Marceau, 1994; Skea, 1994; Tushman & Rosenkopf, 1995). Technological "progress" has become a major social issue, and has become a key component of national economic agendas. This means that some emerging industries are, and will continue to be, very much enacted.

Choosing to not learn, then, is to risk obsolescence (Foster, 1986). In this study, for example, 37 of the 45 firms identified as incumbents -- based strictly on the fact that publicly available business information identified them as being manufacturers of storage batteries -- were never reported in a very large sample size of public media items as pursuing innovations intended for the EV market. Theory says (Tushman & Anderson, 1986; Utterback, 1994) that these 37 firms (or at least the subset which concentrated on manufacturing Lead-Acid batteries) were all risking obsolescence to the extent that electric vehicles would someday replace internal combustion engine automobiles, either in niches or eventually on a grand scale.

On the other hand, it would be premature to imply that strategists in these 37 firms were necessarily being foolish in their risk-aversion. In the first place, the U.S. "market" for electric vehicles had been mandated by political decree, which is probably one of the more tenuous business realities. This particular decree created a stable and excellent experimental setting, but it really mandated supply, not demand. Political will, or at least political power, was not certain to remain stable in the long-term, and neither was the requirement to produce EVs. Second, if the major automobile manufacturers failed to develop road-worthy electric vehicles, they faced massive fines or expulsion from doing business in California, not the battery manufacturers. Thus the demand for advanced electrochemical devices was actually coming from the automobile manufacturers, not automobile purchasers per se -- at least not yet, and not for a long time. The real market for EV power sources was very much being circumscribed by the strategic goals of the automobile manufacturers, whose sentiments and agendas were mixed to say the least (Cronk, 1995). Third, there seemed to be a reasonable amount of time (even in strategic terms) to monitor the EV industry and join it later as close followers. On this point, it is important to recall the irony that the instigators of technological discontinuities have been found to rarely be the proprietors of the eventual (legal or de facto) dominant design (Anderson & Tushman, 1990; Utterback, 1994). Fourth, the market for automotive Lead-Acid batteries would shrink only as fast as the EV industry developed, giving incumbents time to re-orient themselves (to re-learn and re-enact their environments) towards other more certain and exciting markets -- true markets -- for stored, portable electric power. Even then, if the EV industry did succeed, and especially if it succeeded only in niches, it is conceivable that the market for even the prevailing dominant design might continue to grow, as global economic integration progresses, trade barriers continue to fall, and the demand for simple, reliable and low-price (automotive and other) products grows in developing nations (Porter, 1990).

Despite the main implications of Technology Cycles frameworks, then, SIC 3691 firms who were avoiding the EV market should not automatically be impugned for their risk-aversion, because their competences were related to basic user functionalities that varied in detail but were consistently promising. The silent 37 SIC 3691 players might in retrospect be understood as having been strategically wise, technologically competent, and politically shrewd. In the long run, the results of this experiment might suggest that Technology Cycles frameworks be extended to consider unstable political agendas (Tushman & Levinthal, 1995), munificent market opportunities (Tushman & Anderson, 1986), and globalizing environments (Whiston, 1994).

But indeed, over 100 firms from a wide variety of industries and nations were determined, to various extents, to refute the "you can't mandate technological breakthroughs" naysayers, and long-term results of the experiment were not at all certain. Either way, the relative (political) artificiality of the "market" did help make this scenario an almost pure example of "technology push" -- the creation, based on scientific knowledge and engineering acumen, of devices with substitution (price/performance) characteristics that hopefully would be attractive to the point where at least pioneer-type consumers would purchase them, en route to much grander schemes (Goodman & Lawless, 1994; Rothwell, 1994). At the level of the EV itself, the "push" needed was so comprehensive that clean-sheet automobile designs were thought by many to be necessary. From this focus, a clean-sheet product-type was driving the creation of, in effect, a clean-sheet industry. And because advanced systems engineering was such a critical ingredient to the overall mix of required competences, it was often difficult to disassociate the EV industry from the EV power source industry. So the EV power source industry was clean-sheet itself -- already global, full of joint ventures and alliances, organized into non-pre-existing coalitions, and being led by a diverse front of the most technologically competent players, whoever and wherever that might be (Marceau, 1994; Cronk, 1995).

When industry incumbency was originally operationalized, it was argued that firm size did not automatically confer or penalize firms' abilities to innovate (Pavitt, 1994; Rothwell & Dodgson, 1994) -- hence all SIC 3691 firms were considered equally likely to be non-innovative or incrementally innovative. The results of incumbent activity have been assessed at length. At this point and in the same vein, it is interesting to note that, also as expected, not all newcomers to the industry were small, young, and stereotypically entrepreneurial. Some very big concerns with some very deep pockets were innovating aggressively (e.g., 3M, AT&T, Delco, Fuji, Hewlett-Packard, Hitachi, Lockheed, Matsushita, Samsung, Sony, and Westinghouse), and seemed very capable of employing material rather than organizational advantages to their innovation efforts (Audretsch, 1995). Many small companies were of course evident, and some were new start-ups and spin-offs from the extant automotive industry (e.g., ECD, Electrosource, and Ovonic). Morphologically speaking, one would intuit that some newcomers had come from afar (e.g., AT&T, British Aerospace, Johnson Controls, and Lockheed) while others seemed to be morphological neighbors (e.g., Powercell, Trojan , and Japan Storage Battery). Geographically, of course, the point is more obvious; newcomers came from such places as Israel (ZincAir), Russia (Sovlux), and many triad nations.

One "extreme" kind of newcomer that was conspicuously absent in the public media, however, was the backyard or basement tinkerer. Whether or not much basement tinkering was actually happening was arguable. On the one hand, and as previously discussed, one would not suspect that unorganized activity would automatically (or institutionally) attract widespread attention (Herman, 1995). On the other hand, there were many public media items that focused specifically on backyard tinkering in EVs themselves. Perhaps whole electric vehicles were simply more newsworthy than specific electrochemical devices being designed for electric vehicles. The intent of this short discussion was not to renew the analysis, but to make it clear that no particular point of view, framework, or theory which identifies the "typical" frame-breaking innovator was strongly supported or rejected in this study, except one; non-incumbency was a nearly ubiquitous characteristic of new industry players (Tushman & Anderson, 1986; Anderson & Tushman, 1990; Utterback, 1994).

In other words, the new industry (EV, EV power source, or an integration of them both) certainly was not emerging as the youthful image of its industrial antecedent. The extant automobile industry is oligopolistic, and the major automobile manufacturers in a sense dictate to a vast hierarchy of suppliers in their respective industries (Cronk, 1995). In contrast, the EV industry(ies) already had characteristics similar to contemporary powerhouse industries -- electronics and computers in particular, as well as a touch of aerospace, specialty materials, and chemicals (Cawson, 1994; Hobday, 1994; Sharp, 1994). The new industry seemed to be aggressively adopting the lessons learned by other industries, rather than poised to merely repeat the evolutionary pattern typical of other long chapters of American industrial history (Chandler, 1962).

Perhaps a more profound observation concerning the way the industry was beginning its evolution, however, is that relatively small "gales" have the potential to cause massive "destruction" (Schumpeter, 1976). In this research setting, in fact, it was the least competence-destroying innovations that had the most dramatic implications for not only industrial change, but overall socio-economic and techno-economic change as well.

To illustrate, consider that if Lead-Acid Batteries could be quickly and inexpensively improved enough to yield a level of practical specific energy that would result in minimally acceptable vehicle range (but could never be improved much beyond that point for phenomenological reasons), this would place extreme demands on other, very truly synergistic EV technologies such as aerodynamics, tires, lightweight composites, environmental control systems, and electronics management systems, to progress rapidly so as to maximize their abilities to contribute to solving the basic range problem. (Here, "minimally acceptable" means a level of performance acceptable to the mass market, an entirely arbitrary expression that was chosen only to make the following points distinct.) Thus a minimally acceptable Lead-Acid innovation would, for practical purposes, require the most extensive and systemic renewal of automobile technologies. As previous discussions made clear, however, this was not the only kind of broad change that would probably be triggered. A society full of Lead-Acid Battery-powered EVs, due to their inherently low phenomenological ReDox potentials, would require the most elaborate extension of power grids, since Lead-Acid Batteries would require the most frequent recharging of all options.

And there is more. Where the generation of electric power is relatively clean (e.g., hydroelectrical, nuclear, wind, or solar), the net pollution benefit of electric vehicles was fairly obvious (MacKenzie, 1994). But in places like the heavily populated northeastern United States, where a great deal of electric power is still generated by burning coal or oil, the net pollution benefit of electric vehicles was very arguable. To some analysts, very widespread use of EVs seemed senselessly disruptive unless the electric utility industry was also overhauled (MacKenzie, 1994). Extensive replacement of internal combustion automobiles with Lead-Acid-powered EVs, then, would cause and/or encourage widespread disruption of lifestyles, endless temporary inconveniences as power grids were extended and made more elaborate, the destruction of the extant automotive paradigm, and the regional overhaul of a large part of the electric power generation industry. Other storage batteries -- Other ReDox and Hot Batteries in particular -- would of course have the same general effect, though their greater phenomenological potentials might allow a lower level of disruption to socioeconomic infrastructures, and place less pressure on other automotive technologies to advance.

Ironically, the more "competence-destroying" electrochemical innovations might have less disruptive overall effects. Devices like Zinc-Air Batteries and Common and Hot Fuel Cells would destroy the competences of Lead-Acid Battery manufacturers, and would also cause a paradigmatic change to the automobile industry. But because of their high phenomenological potentials, they would not absolutely mandate a total re-engineering of the entire automobile concept. Fuel cells, in fact, would only require extensive vehicle redesign, not such total re-engineering that re-invention is really the more accurate word. Also, in this simplified scenario, since these devices would require replacement of reactant materials/fuels, power grids would not need extension and elaboration, the electric power generation industry would not need an overhaul, and lifestyles as they relate to the "car" would not be different. Owners would have to patronize filling stations, of course, and in the short-term it might be difficult to find stations selling Zinc cassettes or whatever hydrogen-based fuel emerged as the best choice for fuel cells, but never would a vehicle need re-charging, publicly or privately. Of course, these descriptions are general, while the full details are much more elaborate and controversial. The above points were specifically chosen not to take any position of advocacy, but merely to illustrate one particular set of possibilities that is related to theory.

The main point of making this contrast is that small discontinuities on one level of analysis can cause large discontinuities at higher levels of analysis, while large discontinuities on the same initial level of analysis can be less disruptive at the higher levels of analysis. Alternatively and more conservatively, the more general assertion is that different low-level discontinuities can trigger different upper-level discontinuities, whether or not they are of the same magnitudes.

This theoretical point is easily translated into a practical implication. It would be wise for a strategist of any type to think through the multi-level ramifications of an argument for or against any particular technological innovation. The "let's be conservative and introduce little changes at a time" view of technological progress can be strategically unsound because markets and communities might be unwilling to make massive economic and psychological adjustments for small gains in performance, and rightly so if less disruptive choices seem realistic, albeit farther off (Granstrand & Sjolander, 1994). An entire new industry can be foiled in the process, and be rather easily defeated on political grounds. The "let's work long and hard at the pre-commercial stage and then score a 'big hit'; let's not ruin the market early" view is no doubt justifiable in some scenarios. Policy makers ambitious for social change might take very great care as well.

An ancillary implication is that technological "progress" is path-dependent (Coombs, 1994; Freeman, 1994; Lissoni & Metcalfe, 1994; Arthur, 1995; Cohen & Levinthal, 1995). That is, small decisions at one point in time can have enormous future leverage. At least during the period of time under study, it was unclear which specific electrochemical couple, innovation, or even PT would win over any extended period of time, and the previous discussion only hinted at how complex the overall issues were. But obviously, once product substitution started occurring and larger-scale socioeconomic infrastructures started developing or changing, it would only become more difficult with the passage of time to engender renewed paradigmatic change. Here, long-awaited breakthroughs in some PTs or in specific innovations -- even huge breakthroughs making impressive leaps in performance -- might be much too late if even modest, short-term innovations gained early market and social appeal and fostered appreciable, socially paradigmatic sunk costs. In more strategic terms, a generational approach to new product introduction, by either one or several firms, seemed problematic unless all expected generations morphologically adhered to the same, or very similar, grander vision (Wheelright & Clarke, 1995; Wheelright & Sasser, 1995).

On that note, this scenario also illustrates how truly important are the implications of establishing "share of mind" (Prahalad & Hamel, 1994) in new, uncharted and unstructured competitive space. The "popularization" of Lead-Acid, Other ReDox and Hot Batteries, *collectively*, was a very important observation. Regardless of which PT would eventually win, or regardless of how specific ReDoxes might come and go in the relatively foreseeable future (Figure 6.1), all of the innovations defined by these PTs were part of a similar trajectory, or paradigm, being established in the collective mind of potential future consumers. Ironically, the more often the pros and cons of each specific PTA, PTB, and PTD innovation were argued, the more cognitively legitimate became the paradigm it symbolized, or the vision it conjured. Even competition on a head-to-head basis was popularizing in the minds of readers and listeners expectations about the operating characteristics of electric vehicles, what society might look like if the California mandates worked, and what it would cost not only in terms of the exorbitant price of vehicles, but also in terms of non-trivial economic externalities.

The above descriptions also allude to another important implication for theory. If it is reasonable to assert, as this study has shown , that a carefully developed morphological analysis can explicate parameters in a way that identify core competences, the potential structure of new markets and industries, and technological trajectories that can redefine whole communities, then it is also reasonable to assert that these parameters have the potential to be technological delimitations of strategic groups. In the situation described above, for example, the competition among PTA, PTB, and PTD innovations that resulted in so much media attention might be interpreted as a form of tacit collusion, "contrived deterrence" (Caves & Porter, 1977) to the entry of technologically superior alternatives using morphological non-complementarity as a mobility barrier. It is perhaps the case that extant understandings of strategic groups underestimate their technological underpinnings and phenomenological antecedents.

Finally, there are interesting research implications of the "technology is competence, but competence should be tacit to be competitive" dilemma. In prior discussions it was noted that Strategic Management research has always been very well-fed (qualitatively and quantitatively) by research in Economics, Marketing, and Administrative Behavior. It was also noted that these fields developed views of technology that missed its central role, so Strategic Management inherited a flawed view of technology. At this point of the study, since it has become appreciated both in theory and in findings that technology is competence, but that truly competitive competence is tacit and unobservable, it would be especially harsh and inappropriate to suggest that these fields should have developed views of technology that fully grasped and theoretically developed its central role. The contributions that these fields have made to the understanding of technology have understandably been limited to observing not technology, but the artifacts of technology germane to specific theories (e.g., number of patents in Economics, product differentiation in Marketing, and innovative cultures in Administrative Behavior). The real point, however, is that if technology really is one of the centrally important dimensions of Strategic Management, then the field should endeavor to develop a tacit understanding of technology of its own, through much more cross-disciplinary research, which obviously means joint research with Science and Engineering scholars. The other more traditional fields can not and should not be expected to supply the ability to understand technology at a level of understanding that borders on intuition. The most ironic implication of this dissertation is that technology has been relatively misplaced in Strategic Management research not because it is a secondary or peripheral issue, but because it is so elusive and difficult to grasp -- precisely the reason it is so strategically important to practitioners.

To summarize this section, a major implication of the results of this study is that the Resource/Competence-based view is indeed an appropriate framework to use when focusing on the central importance of technology in Strategic Management. Despite many complexities, "technology is competence" facilitated a consistently fluid approach to, and subsequent management of, a difficult integration of considerations. Operationalizing any kind of competence is difficult-to-impossible because of observability problems, however, so proxies are almost required. In this study, combinations of phenomena in product innovations were successfully used to represent fundamental kinds of knowledge that were their fountainheads.

Second, small discontinuities in technology on one level -- which is the same as saying small discontinuities in the development and application of knowledge and learning -- can trigger large disruptions on other levels, and vice versa. (Each scenario is likely to be idiosyncratic and bears extensive and careful scrutiny.) By implication, modest discontinuities are not necessarily more likely to be accepted than more radical discontinuities. Technological conservatism can be a risky strategy for reasons that go beyond the basic implications of s-curve and Technology Cycles frameworks. An associated irony is that complete risk-aversion (inactivity) in the presence of possible discontinuous technological change is not necessarily foolhardy, especially in the presence of strategic alternatives. Thinking in terms of competences and user functionality helps bring these alternatives into focus.

Third, there are possible conceptual links among phenomenologically-defined technological trajectories and paradigms, the establishment of mind share in future competitive space, and the early stages of strategic group formation. What seems certain is that early technological decisions, however modest, can have enormous leverage and almost intractable results.

Fourth, new industries can resemble contemporary successful industries at least as much as they can resemble their immediate ancestors. New high-tech industries might never have to go through classic evolutionary stages in order to become highly sophisticated in many ways. Fundamental management principles and techniques are public knowledge and the pioneers of new industries should be expected to capitalize on lessons learned by others.

The implications discussed in the sections that follow are not necessarily less strategically important than the implications discussed above and should be considered to be extensions, focused on particular streams of literature.

Management of Technology

As implied by specific references, portions of the preceding discussion could have been framed Management of Technology issues as cogently and comfortably as they were framed Strategic Management issues. Without being redundant, at this point it will simply be re-emphasized that technology is such a strategically important management concern that demarcations between some samples of literature are no longer clear. This section focuses specifically on the literature which describes s-curve and Technology Cycles frameworks, which constitute the bedrock of this dissertation.

The main implication concerning s-curves and Technology Cycles frameworks is how extraordinarily useful they are, despite their limitations. To the extent that s-curves (at any level of analysis) can be predicted, plotted, or derived, some dynamics seem certain to be associated with their shapes and relative positions. Recall, for example, that most of the statistical tests of the main hypotheses in this study either rejected or failed to reject the null hypothesis by such wide margins that even the inherent imprecisions of the test methodology paled. (That is, tests of most hypotheses either rejected the null hypothesis at alpha = .01, or sometimes .001; or they failed to reject the null at alpha = .1 or cutoffs even well above that figure. Thus very few test results were uninterpretable because of the limitations of the methodology.) But some test results contradicted each other, thereby insinuating theoretical contradictions as well.

When the tests were revised and the analysis extended to consider available technical and symposium data, however, it was found that the contradictions among the results of testing the original hypotheses were easily explained. The pattern of cognitive legitimacy was, with only a few important exceptions, accurately reflective of the pattern of actual overall industry activity (not the pattern of legitimacy that was expected to result from incumbent manipulations), which was proceeding very much in agreement with what Technology Cycles frameworks would predict. In other words, the momentum of actual Technology Cycles in-the-making was so potent that media patterns were not, in aggregate, dissuaded from depicting them truthfully. Without the aid of s-curve and Technology Cycles frameworks, it is difficult to speculate what the interpretations of the original test results would have been. It suffices to say that the public media should not be impugned for biased reporting, when in the aggregate reports generally agree with the technical truth. Whether or not the pattern of public awareness (legitimacy) had a momentum and possible impact all its own is not presently the issue.

Of course, s-curves and Technology Cycles frameworks are themselves human inventions, intended to help make sense out of a certain type of multidimensional and complex human endeavor. In their simplest forms they describe the unidimensional performance growth, exhaustion, and replacement of technologies, in environments that are assumed to be mostly unencumbered by forces other than the intentional human effort to make technological progress. Yet the present scenario made clear that this ostensibly simplistic framework is rigorous enough to withstand some severe complications and encumberences. The following discussion provides an explanation.

As discussed in the literature review, s-curves and Technology Cycles are composite understandings of the results of the work done by many scholars and practitioners. Naturally, some work has become more popular than others. The view presented most forcefully in this dissertation can be most succinctly understood to be a combination of the work done by Tushman & Anderson (1986), Anderson & Tushman (1990), and Utterback (1994). Briefly, this view holds that a technological discontinuity (wherever its genesis) initiates a period of ferment, a relatively wild and economically undisciplined competition among ideas and products all based on the opportunities made possible by the basic discontinuity. Sooner or later, and after a very complex and idiosyncratic set of events, (usually only) one configuration comes to dominate the scene. This design becomes so dominant in the marketplace that non-adherents face the extreme probability of failure, while adherents struggle, over a period of stability that can last decades, to basically either differentiate the dominant product design in some value-adding way or continue to lower its cost/price through process innovations. Eventually because of inherent natural limitations, significant performance improvements can only be accommodated by the inauguration of another discontinuity, and the drama is renewed (as discussed at great length during the development of propositions and hypotheses).

The conditions of the natural experiment chosen for this dissertation were not so simple; in fact, they were very convoluted. First, the discontinuity which triggered the period of ferment was not technological, it was political. The State of California socio-politically legitimated (not to be confused with cognitive legitimation, which is simple awareness-building (Aldrich & Fiol, 1994)) -- in fact, mandated -- a technological regime that was profoundly rewarding to (or coercive of, depending on one's point of view) innovation of a pre-conceived type. The (hoped-for) technological breakthrough was in the future, not the recent past. Furthermore, due to the path-dependent nature of technological trajectories (see previous section), the technological breakthrough in this scenario stood a very good chance of defining the dominant design, instead of triggering the wild competition for one. In sum, instead of complying with the technological discontinuity-ferment-dominant design-stability model of Technology Cycles, the present scenario looked more to be political discontinuity-ferment-technological discontinuity/dominant design-stability.

Yet despite this extreme practical distortion of the theoretical model, the basic dynamics of s-curves seemed unperturbed. A dominant design was evident. It had an early lead in performance and cost/price. But to some, its phenomenological limitations cast a dark cloud on its future. Alternatives clearly had higher potentials but most were not yet commercializable. And they were all expensive, or at least they would be in the short-term. In general, the higher the performance potential of the alternative, the higher its cost, and the less clear its imminence. Competences required to bring these alternatives to fruition were discontinuous from the core competence of the dominant design, so non-incumbents were, for the most part, enacting the industry and most of the ferment. There were a few exciting exceptions, of course, but identifying exceptions is an important part of the practical utility of Technology Cycles frameworks -- the identification of some exceptions indicates fidelity, not failure.

In sum, the implication is that whether technology is pushed or pulled, mandated by law or demanded by consumers, socio-politically simple or complex, s-curve dynamics seem to be stubborn masters. S-curve dynamics are so pervasive, and associated frameworks are so rigorous, that any explanation or theory of technological progress (at least at the level of the firm or industry) that does not consider them carefully runs a high risk of being badly underspecified. S-curves are theoretically sophomoric, but they represent fundamental dynamics.

As important as they are, however, s-curves and Technology Cycles are imprecise. It is one thing to plot the paths of historical events and note persistent patterns of technological progress; it is another to extrapolate recent progress far into the future and be correct. Consider once more Figure 6.1. At face value, the figure implies that Lead-Acid Batteries might not be worthwhile developing, since their s-curve lies below the s-curves of all the other batteries presented in the figure; and at the other extreme, that Zinc-Air Batteries are so phenomenologically superior to other choices that they are almost destined for success. Between these extremes, the general interpretation is that batteries that are superior in the short-term might not be the best choices for the long-term.

But these straightforward implications can become complicated quickly, and reasonable changes of basic assumptions can have radical effects on expectations. First, the passage of time will not, of itself, cause technologies to progress. As a dimension of the figure, time is merely representative of cumulative R&D effort (Foster, 1986). There is never any guarantee that R&D effort will get results, especially specific results. Second, though specific energy is the appropriate performance consideration, and though this was argued to be related most importantly to ReDox, it is likely that the comprehensive set of obstacles encountered along each s-curve is or will be seen to be relatively unique. Previous discussions have alluded to various and sometimes idiosyncratic producibility problems; likewise, ReDox is phenomenologically interactive with other performance parameters such as specific power, depth of discharge, recharging time, etc. Getting each electrochemical couple to yield its potential is a unique and complex problem of managing trade-offs, as well as simply pushing out one unidimensional frontier. It should always be remembered that s-curves depict only one performance parameter at a time, that most complex products have more than one performance parameter that is of keen interest to both technologists and consumers, and that there are likely to be phenomenological interactions among several technical constraints.

Third, it is very important to realize that the actual s-curve of any battery will probably never reach its phenomenological potential. These potentials are indeed upper limits, but practical specific energy (specific energy delivered to the wheels) was in all cases expected to be a fraction of its theoretical specific energy. In other words, in this scenario upper limits were optimistic; experts agreed that they would never be nearly fully exploited (Chemtech, 1994). The reason this practical observation is theoretically important is because in the extant literature, s-curves are usually depicted as "topping out" very near their theoretical upper limits. Theoretical upper limits are derived from scientific knowledge of how nature works. In many cases, however, the engineers' task is much too daunting to expect such radical levels of efficiency. As such, using specific s-curves in the forecasting mode should take into account practical (engineering) as well as theoretical (scientific) limitations.

Examining the general development of Lead-Acid Batteries helps illustrate how important this observation can be. After many decades of development, the practical specific energy (25-40 Wh/Kg) of Lead-Acid technology was still only about one-sixth of its theoretical specific energy (175.7 Wh/Kg). It can be assumed that the former figure is about where returns to R&D effort became ineffective; that the s-curve of Lead-Acid technology flattened near this practical limit. The Lead-Acid s-curve depicted in Figure 6.1 is really a depiction not of the latest segment of its overall, century-long s-curve, but only the renewed effort that has been described previously as the sailing ship phenomenon (hence its irregular shape).

Finally, since an underlying premise of this dissertation is that innovation is pursued with commercializable performance improvement and profit as its ultimate goal, not random invention for its own sake, s-curve development is probably interactive with cost and price characteristics. Obviously, cumulative production is very closely associated with cumulative sales, cumulative sales is generally negatively associated with price, and price is generally a reflection of cost. Unit costs fall as cumulative production rises, and sales/production volume has an impact on organizational learning and overall experience curve effects (Goodman & Lawless, 1994). Therefore the rate of growth of firm-level s-curves is probably positively associated with cumulative volume, and is probably negatively associated with cost and prices. The strategic implication, of course, is twofold; the development of s-curves can be accelerated if costs can be contained and this containment is translated into lower price; and s-curves can be retarded in their development by high absolute costs which boost prices and inhibit sales. Absolute costs, scale economies, and of course proprietary information are barriers to entry (Porter, 1980) partly because they obstruct the growth of technology s-curves.

So as simple as they seem to be, interpretations of s-curves should take into account certain caveats: returns to R&D are never certain; theoretical upper limits are likely to be optimistic; the critical dimension of performance is not always independent of other important performance dimensions; s-curves of even very similar products are likely to depict different sets of technological hurdles; and though performance is key to innovation and technological substitution, cost and price management is likely to affect the shape of any technology's s-curve. The technicalities of any scenario will make it unique; nevertheless, the above caveats are generalizable to many other situations, particularly those involving complex products.

The discussion would not be complete if the contributions of the other authors noted in the literature review went overlooked. Interpreting these contributions in terms of the findings of this study will help emphasize, enrich and extend some of the implications made to this point.

Abernathy & Utterback's (1988) argument has become an important cornerstone of the Management of Technology literature. Again, they identified the first stage of technology development as "Fluid" -- the period of time when functional performance is key, product users are the prime stimuli for innovation, and manufacturing processes are small scale and flexible. Obviously, in the present scenario all MD>0 innovations were in a Fluid stage of development, except of course that the stimulus for innovation was primarily political. Otherwise, achieving practical specific energy was the overriding goal and there were only a few announcements that mass-production was even imminent. In the "Transitional " stage a dominant design emerges -- the transitional stage in this scenario was likely to be about the same period of time for both electric vehicle power sources and electric vehicles themselves. The dominant EV design was likely (but not inevitably) to be powered by the early "breakthrough" in electrochemical innovations that would meet the (admittedly nebulous) threshold of mass-market acceptability. The Transitional stage was at least several years away. In the "Specific" stage product differentiation is difficult, and cost reductions and quality are key. In the present scenario, products were most meaningfully differentiated by their practical specific energies. Since MD 0 innovations had the lowest phenomenological potential, it was unlikely that anything but a short-term sailing ship phenomenon would differentiate them successfully, in terms of performance. Their cost characteristics were already superior, of course; so much so that they seemed to some to be the optimal technology, despite performance limitations.

Ford & Ryan's (1988) view was oriented towards a practical problem which was not of central concern to this dissertation: at which points and under what conditions should a firm market a technology to other firms, rather than develop it in-house? Answering this question has been the focus of a stream of literature that transcends the scope of this study (Hobday, 1994), but intuition suggests that even some of the short-term dynamics of the present scenario would bear fruitful further examination. That is, characteristics of some devices seemed to fit into Ford & Ryan's phases. Devices in the stack or cell stages of development, as well as MITI's agenda and approaches like Sodium-Polymer technology, would seem to be in the Technology Development phase; technologies in the module or prototype stage would seem to be in the Technology Application phase, or nearing Application Launch; devices like Nickel-Cadmium, Nickel-Metal Hydride, and Zinc-Air would seem to be at Application Launch, or in the early part of Application Growth; and Lead-Acid technology would seem to clearly be in the Technology Maturity phase. Previous discussions have hinted at some of the licensing and venturing arrangements being pursued by several manufacturers. The issue of which firms would be likely to capture the economic rents of their endeavors, however, was left completely unaddressed. Details exposed in this study invite such a study.

Trying to envisage the present scenario in terms of Abernathy & Clark's (1988) matrix is a stimulating exercise. Two corners seemed clearly defined, while the other two seemed to be more in dispute. MD 0 innovations were clearly "Regular" innovations because they built on established technical and product competences, and served to entrench existing skills and resources. This would be true of Lead-Acid Battery innovations in any scenario, of course, even one in which electric vehicles were not considered at all. Then approaching the idea of electric vehicles skeptically and conservatively, MD 0 innovations would also qualify as "Market Niche " innovations because they built on established competences, but improved their applicability in emerging market segments. If the California mandates remained in place, but "breakthroughs" in other technologies were never substantial enough to justify widespread substitution because of their exorbitant prices, then at the minimum, improved Lead-Acid Batteries would fulfill the requirements of, and therefore the demand coming from, the manufacturers of electric vehicles. Again, this conservative view seemed to generate some ironically risky strategies -- in the long-term, true market niches (upscale individuals, commercial and municipal fleets, specific military applications, etc.) would seem much better served by any of several MD>0 innovations. At this (niche) level of socio-economic and techno-economic change, perhaps most MD>0 innovations should be considered to be potential "Architectural" innovations --

those that establish new linkages to markets and users, while creating new industries or reforming old ones.

In the vision that was perhaps mid-range between the most skeptical and the most optimistic, some MD>0 innovations on the strategic horizon seemed capable of performing adequately not only in upscale, commercial, municipal, and military niches, but also of performing well enough to foster the development of a broad "second family car" or "commuting car" niche. Collectively, the size of these markets would probably have a substantial effect on improving cost/price economies. The most optimistic visionaries, of course, understood some MD>0 innovations (and no MD 0 innovations) as having the (phenomenological, and therefore market) potential to be "Revolutionary" innovations -- those that render entrenched technologies and product competences obsolete, but are applied to existing markets and customers. A really "big hit" which would yield a practical specific energy capable of giving an electric vehicle anything like the range that an internal combustion engine automobile has with a tankful of gasoline, would have obvious market potential. In morphological and other terms, only the most radical innovations could possibly compete so well: some types of fuel cells and mechanical flywheels, combined with range extenders like ultracapacitors.

In short, due to the exploratory nature of this study, the propositions and hypotheses were developed in the hope of capturing contrasts between the extremes; between the most incremental (Regular) innovations and the most technologically discontinuous (Revolutionary) innovations. Results of the study were clear enough, and details were rich enough, to suggest but not explain fully, non-dichotomous interpretations grounded in the literature.

Revisiting Burgelman, Kosnik & van den Poel's (1988) contribution accentuates this point. Lead-Acid Battery technology was clearly "base" -- not only materials, but relevant competences were commonly available (imitable and observable) and commodity-like; and improvements in overall performance were likely to be relatively modest, or at least it would be disingenuous to suggest that most of the remaining five-sixths of Lead-Acid's untapped potential was likely to be exploited. Perhaps Nickel-Cadmium technology was the one alternative to Lead-Acid that had already demonstrated the characteristics of a "key" technology; one that exhibited cost, quality, or (in this case) performance characteristics that were a present basis for competitive advantage (Lead-Acid technology was no doubt "key" based strictly on cost). In rough terms, several other alternatives were on the brink of being "pacing" technologies, because they demonstrated the potential to be the basis of competitive advantage -- most notably, Nickel-Metal Hydride and Zinc-Air. Other, less-imminent technologies were the better examples of "emerging" technologies -- technologies that have not yet demonstrated the potential to alter the basis of competition. Fuel Cells in particular were probably best thought of as emerging technologies, because of cost problems and specific technological obstacles (like miniaturization) that seemed relatively intractable.

Of course, this attempt to categorize certain technologies was only suggestive. Demarcations between the different categorizations were not unambiguous, and the scheme might best be thought of as a continuum. But here, it is interesting to note that if base, key, pacing, and emerging technologies are relative positions in a continuum, the above interpretation placed PTA, PTB, PTD, PTE, and PTH innovations in exactly the same sequence. In the present scenario, Burgelman, Kosnik, and van den Poel's scheme seemed related to the morphological concept of "distance", in light of a previous observation that the alphabetical ascendance of the different Phenomenological Types of competence-destroying innovations was really just a more specific way of depicting morphological distance. After all, depicting Phenomenological Types alphabetically rather than numerically was an arbitrary choice, one that was prudently made at an earlier point in this study only to avoid confusion.

To summarize this section, this study has corroborated the general utility of s-curve and Technology Cycles frameworks. Their dynamics seemed so pervasive, in fact, that even extreme socio-political pressures did not seem to seriously distort them. This study has also corroborated several known limitations of s-curves and Technology Cycles frameworks. As forecasting tools, they are imprecise and probably interactive with other technological and business considerations, and it is critical to understand that their usefulness lies mostly in attempting to make interpretations of the relative positions of curves and upper limits. Finally, this study has generated enough detail to make rough assessments of associated and supportive frameworks, which suggested their general validity and opportunities for additional research in the same experimental scenario.

Technological Forecasting and Morphological Analysis

Of the tools available for forecasting technological innovation, Morphological Analysis was selected for use in this study for reasons that have been discussed at great length. This section reviews how well the technique performed, relative to expectations.

First, it should be remembered that morphology is simply the study of form, and that Morphological Analysis is an approach to problem-solving that can be applied to virtually any arena (Betz, 1993). The fundamental objective of morphological analysis is to penetrate a set of conditions until their most fundamental dimensions are identified. Once this is done, the problem-solver is able to consider combinations of options that have not yet been considered, thereby facilitating the innovation process.

When this approach is applied to the problem of forecasting technological innovation, the most difficult part is having, or having access to, the scientific or engineering acumen that enables precise and correct identification of the problem, and/or the patience to learn enough about the area in question so as to not produce an analysis which merely breaks down an existing product into its physical components. Rather, the whole point is to dissect a product into the scientific or engineering principles and phenomena (and therefore competences) which the components articulate in physical form (Betz, 1993). (Even this statement is an oversimplification, because the physical boundaries between components are not always the same as the natural boundaries between/among phenomena, and being able to exploit this very non-superficial realization is the essential opportunity afforded by using Morphological Analysis.) In other words, the technique is conceptually simple, but it can be difficult and time-consuming to implement, and each morphological analysis is unique.

At any rate, the results of morphologically analyzing electrochemical devices proved to be profoundly useful. The morphological analysis developed in Appendix 1 described the fundamentals of these kinds of devices in a way that was (a) guided by the rules consistently found in the literature (Jantsch, 1967), (b) flexible enough to accommodate the idiosyncrasies of the present research issues, (c) replicable and objectively communicable, (d) detailed enough to get into the "black box" of what turned out to be batteries and fuel cells, (e) not powerfully influenced by existing economic or industrial structures like SIC (Betz, 1993; Jantsch, 1967), (f) not so detailed that its usefulness was limited to the insight worthy of an R&D technologist, (g) not so detailed that a strategist could not impute its implications, and (h) not so detailed that the statistical test methodology was rendered impotent. The following discussion provides illustrations of these assertions. They are presented not necessarily in order of their importance, but in an order that facilitates transitions between the main points.

Morphological Analysis showed that outward appearances can be deceiving not only in terms of how devices work, but also in terms of the grand-scale implications of their inner workings. In other words, a systems view of new product innovation should consider how small changes in technology can affect larger paradigms or infrastructures. The obvious example of this was the observation that some batteries will work like fuel cells while some fuel cells will work like batteries, and that the implications of the difference are very important. Specifically, Zinc-Air and Aluminum-Air Batteries (and any other examples of PTE and PTG innovations that might be attempted) will need replacement of reactant materials, which is an operating characteristic that is morphologically similar to the operating characteristics of non-regenerative fuel cells. On the other hand, Regenerative Fuel Cells (PTF) will be self-contained, as the electrochemical process within them will be reversible. They will need recharging by being plugged in for a period of time, like most types of conventional batteries. In short, the analysis conducted in this study showed how some non-obvious groups of innovations would transpose the basic relationship between the consumer and the product-type, while others would not.

An even more glaring example of how easy it is for a casual observer of technological change to overlook important product characteristics concerns the term "mechanical battery". Mechanical batteries are flywheel batteries, devices which rely on the conversion of kinetic energy stored in spinning discs into electricity, not the conversion of electrochemical potential into electricity. Mechanical batteries are so different from conventional batteries that they did not even belong on the same morphological matrix, or map, that was developed for this study -- in terms of the problem *as it was identified.* As such, it is illustrative to note that mechanical batteries presented unique technological problems, such as (a) what happens when a disc rotating at many thousands of rotations per minute reaches fatigue and comes apart only a few feet away from automobile passengers, and (b) what happens, because of the natural laws governing gyroscopy, when an automobile tries to go uphill or turn sharply; flywheels are essentially gyroscopes and gyroscopes have tremendous angular momentum which resists displacement in certain directions relative to the plane of spin. During the period of time under study, it must be conceded that these and other problems associated with mechanical batteries were being successfully addressed. The point of the above discussion is twofold; (a) terminology should never be automatically associated with an underlying morphology; devices with similar nomenclatures can be very morphologically different; and (b) as morphological distance increases, technologies generally differ; in particular, devices which belong on different morphological matrices/maps are very likely to be associated with very different competences.

So depending on the research issue, contrasts between matrices/maps can be so clear that the strategic implications can follow intuitively. Contrasts within maps are more problematic. For example, the present problem was identified so as to enable a consistent focus on only electrochemical devices. Here, statistical analysis of the tests of the hypotheses might well have been hopeless in the absence of some attempt to group devices according to their phenomenological characteristics. Recall that in many of the frequency tables, some of the expected frequencies in individual cells were low, even when they represented entire Phenomenological Types of innovations. By extension, had each electrochemical couple been deemed its own Phenomenological Type (i.e., Lead-Acid=PTA, Nickel-Cadmium=PTB, Nickel-Metal Hydride=PTC, etc.), it is doubtful that tests of most of the frequency tables would have been statistically interpretable. Anyway, doing so would have been anathemic to the idea of mapping out future competitive space, because all it would have done was analyze the list of the ideas presently being considered, making no connections among morphological variants which, in the view that emerged in this study, mapped different *within-matrix* trajectories.

Next, during the development of propositions and hypotheses, this study carefully acknowledged the known limitations of Morphological Analysis, particularly the caveat that Morphological Distance should not be used too literally or in a cavalier way. Yet results of this study indicated that Morphological Distance, albeit crude and metaphorical, does have the ability to do more than just identify dichotomous groupings of innovations. On the one hand, using Morphological Distance (1, 2, 3, and 4) to represent groupings of innovations based on how many parametric options were switched would have been misleading because it would have resulted in morphologically different innovations sharing the same MD. But when the fundamental idea was pursued more rigorously, and morphologically distinct *combinations of options* were grouped into Phenomenological Types, statistical results were interpretable, often to the point of being obvious.

Furthermore, the alphabetical ascendance of PT was qualitatively observed to be related to what one would expect to be the characteristics of innovations that were more competence-destroying than others. That is, the alphabetically "higher" PTs seemed to be more expensive, less commercially imminent, phenomenologically superior, and pursued by fewer players than the "lower" PTs, and the few incumbents pursuing competence-destroying innovations were all pursuing innovations of low PTs.

In the same vein, Morphological Distance corroborated the idea that innovation is usually pursued with profitable commercialization in mind, not random invention for its own sake (Arnfield, 1969). Recall, for example, that the alphabetical ascendance of the PTs of the specific batteries presented in Table 6.5 was precisely associated with the numerical ascendance of their theoretical specific energies. It would be incorrect to interpret this observation as meaning that all Morphologically Distant possibilities are inherently likely to perform better than Morphologically "Close" possibilities -- because thousands of phenomenologically senseless possibilities (permutations of electrochemical couples) did not appear in the table (Bright & Schoeman, 1973; Jones & Twiss, 1978). It is much more reasonable to suggest that innovators are competent enough to understand how wasteful it would be, especially from a business perspective, to pour resources into the difficult and uncharted development of a morphologically distant possibility unless it was known or at least theoretically suspected to have superior phenomenological potential.

Also, no natural law says that the first innovation of its kind must be the one variant that represents a morphological grouping (of some definition) that will be proven in the long-term to be the most phenomenologically inferior of all possibilities. Some morphologically distant possibilities will be poor ideas and foolish to pursue. It is important for innovators in innovative firms to be open-minded about phenomenologically superior possibilities, not blind to known limitations.

An associated implication is that, as argued during the development of propositions and hypotheses, it is not always necessarily the case that technological progress always means exploration of the "terra incognita", either at the frontier (MD 1) or in leaps (MD>1) (Ayres, 1969). Metaphorically speaking, sometimes it can be worthwhile trying to go backwards, to re-examine "territory" (besides MD 0) that has been explored before. In the early part of this century, for example, Thomas Edison was convinced that electric vehicles were, on the whole, superior to both gasoline and steam-powered automobiles, but noticed precisely the same technological bottleneck that was at the heart of this dissertation -- limited range. So in his indomitable way, he invented and according to him, perfected an actually quite good Nickel-Iron battery (Schiffer, 1994). It is humbling to note that Nickel-Iron technology was one of the very viable options being re-visited as of 1993-1995.

Next, it is interesting to note how easily Morphological Analysis identified the critical performance parameter (phenomenon), which by virtue of the attention it attracted, was interpreted as being the core competence. On the other hand, the discussion that laid the foundation for the morphological matrix developed in Appendix 1 suggested as much anyway. In a sense, the other three parameters and their options were somewhat obvious derivations of the choice of a particular electrochemical couple. But only through a discussion which started from a consideration of nature's fundamentals did the obvious become obvious. In contrast, consider Figure 2.1 (Zwicky's original morphological analysis of jet engines). In that matrix, the core phenomenon and core competence are far from obvious, except perhaps to an industry insider who has comprehensive expertise in a broad range of aerospace technologies. The relatively pedestrian properties of electrochemical technologies made the present analysis so easy to understand, that their morphology sometimes seemed to be redundant to common sense. The exotic natures of many other product technologies, which are not nearly so obvious and demand competences truly unfamiliar to the casual observer, are only so much the better as candidates for an industry analysis focusing on the morphology of its products' technologies.

Similarly, since reduction-oxidation was so clearly the key parameter, technology, and competence in terms that were meaningful to this study, it would be interesting to redefine the original problem and perform a more penetrating analysis. In other words, from the point of view of this study, it was appropriate to consider reduction, oxidation, and the catalytic contribution of electrolytes as being so dynamically interrelated that they were considered to be one phenomenon. Now that the importance of that phenomenon is so clear, it would be appropriate to renew the analysis focusing specifically on the basic, much more intellectually challenging elements of that core technology. The apparent legitimacy of storage batteries underscores the potential usefulness of such a study.

In the above discussion, the most crucial implication is perhaps the most subtle. As is the case for many other problem-solving techniques, it is absolutely essential in Morphological Analysis to spend whatever amount of time that might be required to correctly identify the problem as it relates to the issues of keenest interest. The California mandate created a relatively well-identified and neatly-bounded socio-economic and techno-economic experiment, worthy of academic scrutiny. Even though the problem seemed clearly defined, however, this study still encountered boundary problems such as correctly defining industry and incumbency. Had the problem been identified more abstractly -- for the sake of argument, had the problem been identified as the development of an automobile that did not depend on the internal combustion of gasoline for automotive power -- any or all of the following possibilities would have had to have been considered in the analysis: batteries, fuel cells, flywheels, ultracapacitors, turbines, a large handful of "alternative fuels" like propane and methane, and most confusing of all, hybridized versions of all the above. Furthermore, the morphological matrix developed for this problem would also probably have suggested the consideration of pure hydrogen, nuclear, and other fuels. In truth, recent developments in the automobile industry do invite such a study (Betz et al., 1995; Keys, 1993; Keys, 1995). The present study was exploratory, however, so it was focused on a well-defined contrast of conflicting groups of technological alternatives. Again, the point is that definition of the problem is the most important part of conducting a valid morphological analysis. Even subtle differences in the definition of a problem can have very great impacts on the identification of the main parameters of the problem and the options available for implementing each required phenomenon.

At any rate, the results of this study imply that when empowered by analytical forecasting tools like morphological analysis, discontinuous technological change can be studied in real-time. Of course, this statement rests on the observation that it was possible to identify specific technologies (competences) and roughly gauge their relative potentials to enhance or destroy an extant technological paradigm. It was not possible to confidently make specific forecasts, but it was possible to group competences into very different and socially meaningful trajectories. It was also possible to observe how the dynamics of relatively open competition might establish a specific trajectory, possibly at the expense of other trajectories that might be uncomfortably exotic to common consumers, but might be potentially superior in the long-term. However, once more it is necessary to emphasize that the analysis and discussion presented in this dissertation should not be interpreted as taking any position on the very volatile EV issue. Certain events and possibilities were specifically chosen to help illustrate a simple point: that which is becoming popular is not all that is known to be possible, but that which is becoming popular stands a good chance of becoming permanently entrenched.

A final implication in this area considers the passage of time between the initiation of this study and its pending completion. As of early 1996, the basic framework of conditions had not changed (de Neufville, 1996). But deadlines were no longer very far off, at least not in strategic terms. It will be informative to compare the dynamics of the emerging industry as deadlines arrive, to the dynamics which were happening during the period of time when deadlines were not ominous. Retrospection accomplished in years subsequent to the deadline should prove equally informative.

Summarizing the implications discussed in this section is straightforward. Morphological Analysis is a general approach to problem-solving that has important potential towards improving the ability to understanding technological progress.

Naturally, as is the nature of most tools, it is only as useful as the user is skilled. It affords the opportunity of viewing technology inside the "black box" of a product type, but not in such great detail that the opportunity to see general trends, or perform objective statistical tests, is lost. Surprisingly, the Morphological Distance metaphor is indeed useful, but it is only a metaphor and should not be interpreted as possessing strict one-to-one correspondence with implied discontinuities. Morphological Analysis has no level of analysis limitations, but adhering to a carefully developed problem specification is critical to its utility. As hoped, the technique was very useful in studying technological discontinuities in real-time, though retrospection will probably always be the sterner judge.

Institutional Theory

This dissertation did not challenge Institutional Theory as much as it assumed its general validity, especially the validity of the concept of cognitive legitimacy. It was asserted that as industrial structures change, the competition for future competitive space is, early-on, partly the competition for share of mind (Prahalad & Hamel, 1994) and that establishing share of mind is essentially a matter of awareness-building, or of establishing cognitive legitimacy (Aldrich & Fiol, 1994). Since industry players might be prescient enough to perceive this, they might also be expected to actively participate in the cognitive legitimation of their technologies, to the point of pro-actively engaging in attempts to shape media representations of specific technological developments (Aldrich & Fiol, 1994; Rao, 1995). Specifically, this dissertation tested the main hypothesis that entrenched and powerful industry players -- i.e., incumbents -- defend the destruction of their competences and technologies by engaging in information campaigns which are designed to promote the advantages of their technologies and attack the disadvantages of the technologies of new entrants.

However, in this study the activities of only 8 of 45 incumbents were reported at all over a two-year period, in several thousand media items. In terms of the main hypothesis, this finding could be interpreted several ways. The most obvious interpretation is that the tests were simply inconclusive. There were not enough incumbent-initiated innovations to enable a sound statistical assessment of how they fared in the media, especially relative to the number of non-incumbents' innovations. On the other hand, intuition suggests that this finding refutes the general hypothesis. Since many hundreds of items reporting the innovations being pursued by non-incumbents did appear in the media, it would be unreasonable to conclude that SIC 3691 firms were very successfully obstructing the cognitive legitimation of impending electrochemical innovations that could render their competences obsolete.

Several implications for Institutional Theory and the cognitive legitimacy construct are fairly direct. First, if it can be assumed that the public media is an instrument by which emerging technologies gain cognitive legitimacy, then it is reasonable to assume that most new cognitive legitimacy will (literally and figuratively) be ascribed to newsworthy events, not the status quo. As obvious as this might seem, the implication to researchers is that when public media items are used as raw data, a bias towards newsworthiness is likely to be present. Observing a pattern of reports in the public media is to observe a pattern of cognitive legitimation first-hand, and is to observe actual industry activity second-hand. This study showed that there can be a disparity between what might be assumed from media reports to be an overall industry profile, and a fuller truth. Most SIC 3691 firms seemed uninterested in participating in a theoretically exciting scenario, but this was not a direct empirical observation; it had to be pointed out as "file drawer" activity (or non-activity).

Rather, the struggle for cognitive legitimacy had the characteristics of a more conventional, direct competition among mostly non-incumbents (new entrants). Here, it proved prudent that reports of disadvantages were considered as well as reports of advantages. Had reports of disadvantages been overlooked, important symmetries and asymmetries might not have become evident. In general, innovations that were frequently reported for their advantages were also frequently reported for their disadvantages -- some innovations simply got more attention than others, and the attention was generally balanced and technically accurate. These symmetries implied that if information campaigns were actually being waged, overall popularization might have been one successful outcome. But there was little widespread evidence of factually incorrect representation of the advantages and disadvantages of any phenomenologically-defined category of innovation.

An important theoretical implication of these findings is that cognitive legitimacy is not an attribute that is simply either absent or present. It is not always true that any notoriety is good notoriety, so all "units" of cognitive legitimacy are not qualitatively the same. Cognitive legitimacy can be absent, present in a qualitatively good way, or present in a qualitatively bad way. Observing that 37 of 45 incumbents were not reported at all is an observation that their phantom innovations were simply not being cognitively legitimated one way or the other in terms that were meaningful to this study. Likewise, some of the higher-performing and more cost-effective innovations were relatively non-legitimate, in the sense that they simply did not get very much media attention one way or the other.

But in general, when a report of an innovation implied that it was (or would be) in some way superior, it gained positive cognitive legitimacy; and when a report of an innovation implied that it was (or would be) in some way inferior, it gained negative cognitive legitimacy. In a previous discussion the former was termed legitimation, and the latter was termed de-legitimation. In scenarios where information campaigns are successful, asymmetries between positive and negative cognitive legitimacy should be apparent.

Interestingly, however, interpretations of the findings of this study indicated that negative legitimacy does not always negate, or cancel out, positive legitimacy. Recall that in the present scenario, the overall publicity (the positive cognitive legitimacy plus the negative cognitive legitimacy) received by three Phenomenological Types (PTA, PTB, and PTD) of competence-destroying innovations was interpreted as being the overall cognitive legitimation of the technological trajectory they collectively represented.

However, this interpretation was idiosyncratic, for several reasons. First, it was focused on the cognitive legitimation of a technological trajectory, to the detriment of the cognitive legitimation of other possible trajectories. The issue of immediate concern was the widespread development of a cognitive profile of what an EV-based society (or a subset thereof) would be like. The issue of which specific device (basically, which electrochemical couple) would "win" was secondary. Furthermore, it was suggested earlier that the former issue was so critical that activities concerning the latter issue could be interpreted as a form of tacit collusion -- collective attention-getting.

From the Institutional perspective, collective attention-getting for the purpose of enhancing the likelihood of a particular technological trajectory is akin to the more manipulative tactics suggested in Oliver's (1991) spectrum of strategic responses to institutional pressures. Earlier it was noted that the USABC was participating in the legitimation of PTB and PTD innovations, though it was not asserted that this largely publicly-funded consortium had any specific technological agenda that was not rationally oriented towards developing the best-performing technologies. Much less subtly, the Advanced Lead-Acid Battery Consortium was privately funded and focused on the development of PTA innovations. Disregarding the specific charters of these two organizations, it is interesting that Oliver specifically identified active membership in consortia and trade organizations as co-optation and influence tactics, respectively. Whether or not it was coincidental, the trajectory that received most of the absolute amount of publicity was completely circumscribed by the activities of these two consortia.

Also, the tacit collusion interpretation hinged on the observation that amounts of positive and negative cognitive legitimacy were about equal; that legitimation and de-legitimation were symmetrical. Asymmetries -- especially had they not accurately reflected the underlying technical truth -- probably would have required a different interpretation. Disproportionate AND incorrect reports of advantages and disadvantages would not have been suggestive of tacit collusion among phenomenologically-defined strategic groups. It would have been interpreted as successful media manipulation, and the idea that strategic groups are phenomenologically identifiable probably would not have presented itself.

Next, it is important to acknowledge that Institutional Theory scholars have always recognized the importance of personal, organizational, and cultural values (Selznick, 1957); in a sense, institutions are legitimized value systems (Scott & Meyer, 1994). Furthermore, the professions have been recognized as being important agents of value creation and change in and among institutions (Scott, 1995). Since it is difficult to identify boundaries between institutional fields (Di Maggio & Powell, 1983), and since it would also be difficult to argue that professionals in one field can not affect institutional processes in another field, it is important to acknowledge that labelling different measures of legitimacy as being positive or negative is ultimately value-laden. That is, choices made by academic researchers are not always value-free, and this includes choices regarding terminology. The very idea that cognitive legitimacy can be either positive or negative is evidence of the ubiquity of values; exercising the idea by specifically appointing such labels is to show, or at least cooperate with, certain values.

The point of this momentary introspection was not to introduce a complicated philosophy to the argument, but to simplify it. Now it can be conscientiously explained that the tacit collusion interpretation was affected by underlying assumptions concerning the nature of the key dimensions of interest, and the way they were specifically measured. For example, it could have been argued that safety, not range, is *always* the most important dimension of an automobile's performance in *any* scenario. Intuition might suggest that reports of a safety flaw, for example, are negative in a qualitatively different and more profound way than reports of mediocre vehicle range.

This argument is not merely academic. During the period of time under study, a Ford EV (nicknamed EcoStar) equipped with a Sodium-Sulfur battery erupted in fire during a public demonstration. The problem was quickly traced to a software problem in the battery's electronics and resolved. But the event itself was reported widely and details of the fire were repeated for many months, even in media items that obviously had other issues as their foci. Obviously, from a strategic and/or institutional perspective, it would not be reasonable to assert that these reports were completely helpful to the effort to advocate the advent of electric vehicles in general, and the introduction of Sodium-Sulfur batteries in particular -- regardless of what the articles otherwise said about vehicle range or cost. Widespread dissemination of the *awareness* of a safety problem -- even one that was successfully resolved -- could be argued to retard, not promote, public *acceptance* of an innovation.

Alternatively, it could have been argued that focusing on any performance parameter other than net reduction in harmful automobile emissions was ultimately senseless, since reducing air pollution was the main goal of the California mandates. On this issue, there was a great deal of debate as to whether or not electric vehicles would have the desired effect. As discussed earlier, in some regions the net effect on pollution might be its exportation, instead of its reduction. Also, it was often argued that the costs incurred by developing electric vehicles would only slow down the development of alternative technologies, and/or that the prices of electric vehicles would never be low enough to have any real effect on taking the small percentage of very poorly maintained vehicles, which cause such a hugely disproportionate percentage of the total automobile emissions problem, off the road (Cronk, 1995). In fact it was often argued that the subsidization that would be required to price EVs attractively would only be borne in the sticker prices of new gasoline-engine models, resulting in a net economic disincentive to improve population-wide automobile emissions. So the "positive" and "negative" legitimation of the chosen characteristics of electrochemical devices, vis-a-vis *each other*, consciously overlooked views which might vehemently argue these labels.

The point of the above discussion and examples is to illustrate that labelling different measures of cognitive legitimacy as being either positive or negative is intuitively appealing, but it is plagued by incessant value-based assumptions and obfuscations. Any reasonably sophisticated product has at least several important performance parameters, and peripheral parameters are not necessarily trivial from all points of view. In the present scenario, it was even possible that each very technical performance parameter -- i.e., specific power, mean time between failure, system lifetime, weight, recharging time, disposability, etc. -- was qualitatively unique. Any disciple of s-curve frameworks should carefully note that technical performance is seldom one-dimensional and never value-free. Any interpretation of the legitimation and de-legitimation of any performance parameter should be crafted carefully as it is likely to be very contextually dependent. Level of analysis, sociological and socioeconomic climate, and researcher perspective are serious considerations.

At risk of taking this point too far, it must also be conceded that cost/price has more than one measure and each can have a qualitatively different meaning. In this study, cost/price was considered in a general sense, but in the most important sense: the total costs of manufacturing electrochemical devices that were the main drivers of the "sticker prices" of electric vehicles. (The cost of any electrochemical device was generally estimated to have at least a doubling effect on the sticker price of a vehicle (Cronk, 1995.)) The exorbitant prices of electric vehicles were certainly impediments to their overall positive cognitive legitimation (or were contributions to their de-legitimation). But sticker price was not the only facet of this general dimension. Others, also partly determined by advancements in electrochemical technology, included replacement costs (which were expected to be extremely high; in some cases, battery packs accounting for half the price of a vehicle would need replacement every two or three years), maintenance costs (which were arguable, because electronics are reliable but the lack of a repair infrastructure would make any repair costly), resale value (which was a conspicuously absent concern), and other total-ownership-cost considerations which are so familiar to any experienced automobile owner -- any of which, especially in the scenario outlined here, could be a more important personal concern than sticker price.

The point is that in this study, performance and price considerations were both simplified to the point of being simplistic. The multi-dimensionality, or at least the multi-measurability of both performance and cost/price suggests that the cognitive legitimation and de-legitimation of technologies is complex even at low levels of analysis. The present study was appropriately focused on practical specific energy and overall production costs of electrochemical devices because they were the main determinants of vehicle range and vehicle sticker price, and maintaining this focus facilitated a relatively clear and simple way to observe the possible advent of a significant technological discontinuity. As naturally "controlled" as this experiment was, however, it was still complicated enough to remind researchers of the extraordinary complexity of technological evolution and revolution.

Next, the Institutional implications of the general technical "accuracy" of the media representations are intriguing. Recall that the statistical tests of the original frequency tables, the statistical tests of the revised frequency tables, and the qualitative analyses of the technical and symposium data, were mostly in agreement. It was concluded that in general, media representations of the industry were accurate depictions of actual industry activity (disregarding the file drawer of inactivity) and the aggregate expectations of the industry players. The most important disparity was that the general public's awareness of the short-term cost/price problems of competence-destroying innovations, relative to the likelihood that these problems would probably be successfully solved in the long-term, did not accurately match the optimism held by industry players.

This was not a trivial observation. It might not be true that the general public was unduly pessimistic about the cost problems facing the further development of electrochemical innovations. Instead, it might be true that the awareness of the general public concerning costs was a better representation of the technical truth than industry players would admit. As was quoted in an earlier discussion, all players seemed to claim that after a period of time, the costs of producing their innovations would meet the long-term cost guidelines set forth by the USABC. Obviously, it would not be to a player's advantage to claim otherwise. Yet players just as consistently claimed to be able to meet the long-term performance guidelines set forth by the USABC -- and the general public did share this optimism. The observation that the general public shared optimism about future performance characteristics, while it did not share optimism about future cost characteristics, begs a meaningful theoretical interpretation.

One plausible explanation lies in the observability of competences. If technology is competence, and if a truly advantageous competence is tacit and unobservable, then a firm's claim about the future performance of a product, especially if the underlying technology is in any sense proprietary, would be difficult to dispute.

Since phenomenological limitations are derived from scientific knowledge, and since scientific knowledge diffuses rapidly, performance limitations are highly credible and easily communicable. But the ability to translate scientific knowledge into consumer functionality is technology, and if technology is difficult to observe, then it would be difficult for outsiders to wage credible counter-claims (or at least well-informed counter-claims) that reports of important, actual or forecasted, firm-specific technological progress were wrong. Firm-specific technological breakthroughs are apparently newsworthy, and simple claims of breakthroughs can be strategically useful.

Ethics aside, it would also be a strategic blunder for a firm to divulge particulars, known only to itself, about claim-related technical obstacles that would likely perplex and stupefy its technologists in both the short and long-terms. It would be foolish for a strategic manager to popularize a technical obstacle, unless mere popularization of the innovation was the more pressing concern. As long as known phenomenological limitations substantiate firm-specific claims, then, the claims are more difficult to successfully dispute than they are to successfully proffer. (The cynical term "vaporware" has even become a common expression of this type of market signalling, a term which in the computer software industry describes premature but effective product announcements designed to stake out market segments before software products even exist.)

Cost and price obstacles, on the other hand, are arguably more visible, and/or related to non-core, observable and imitable competences. In this scenario some cost obstacles were obviously not firm-specific; for example, it was easy to observe that

Cadmium is both rare and expensive, so it was easy to dispute any predictions about the long-term cost/price competitiveness of Nickel-Cadmium Batteries. Less obviously, it might also be true that firm-specific, or at least firm-level, cost containment and abatement competences are relatively transparent, observable, and imitable.

As a simple example, it is reasonable to assume that the cost of producing a battery that needs a thermal control system that is able to reliably and safely maintain a sulfuric electrode at precisely 635 degrees, will be much higher than the costs of producing a battery that requires no thermal control system, other considerations held equal. It could also be argued that such an obvious and expensive requirement is simply very much within the grasp of media professionals to describe and media consumers to comprehend, compared to explanations of many performance hurdles which tend to be either very cryptic (due to the tacitness of technology), or grossly oversimplified (due to attempts to de-mystify technology). In short, it is conceivable that the mismatch between the optimism shown by industry players about the future cost/price competitiveness of their innovations, and the public media's confidence, was attributable to the ease by which cost/price characteristics can be disputed, relative to the difficulties of disputing performance projections.

The implication for Institutional Theory is that in information campaigns designed to selectively guide the cognitive legitimation and/or de-legitimation of specific technologies, claims of future performance might be easier to legitimate than de-legitimate. As long as phenomenological limitations allow the possibility that a claimed or forecasted level of performance can be achieved, the newsworthiness of the claim is likely to promote its diffusion. The more firm-specific the claim -- i.e., the more proprietary the technology -- the more groundless will be the counterclaims of outsiders. (Groundlessness, of course, is not necessarily the same thing as incorrectness. Outsiders might correctly contradict a claim, but not on the grounds that a firm does not possess a competence which can not be observed from the outside one way or the other.)

Conversely, claims of future cost containment and abatement are relatively difficult to legitimate, and relatively easy to de-legitimate. Cost management is a relatively transparent skill, and is comprehensible even on a pedestrian level. Cost problems are fairly obvious and once identified, easy to communicate; optimistic cost predictions based on the inevitability of economies of scale and so forth can fail to address specific solutions to intractable, obvious and comprehensible problems. The results of this study imply that it is relatively easy to sow specific doubts about another firm's claimed ability to overcome observable cost problems; and it is relatively difficult to sow specific doubts about another firm's claimed ability to overcome obscure product-technology bottlenecks.

Intuition suggests that this theoretical possibility underscores the importance of a firm's reputation, and the importance of the idea that legitimacy is generally communicable from an organization to its products (Aldrich & Fiol, 1994). For example, it is possible that some firms reported in the present study, which are highly respected for their innovative prowess (e.g., 3M, Lockheed, and Sony) were able to get more (or more favorable) media attention than some other firms which have not established reputations as being particularly innovative (e.g., General Motors, Rolls-Royce, and Rover).

Individual track records aside, it is difficult to assert unequivocally that the organizational "liabilities" of newness and smallness, which were credibly theorized as injuring firms' abilities to control the media (Aldrich & Fiol, 1994; Rao, 1995), were also inherently injurious to the credibility and newsworthiness of a claim. Whether fashion or permanent change, by the mid-1990's the business climate in the United States was plainly championing the innovative capabilities of young and small firms

(Imperato & Harari, 1994; Leonard-Barton, 1995; Nadler, Shaw & Walton, 1995). Quantitatively big firms were trying to get qualitatively small through organizational realignments, and quantitatively old firms were trying to get qualitatively young through the development of corporate entrepreneurship -- partly for the sake of enhancing the ability to innovate (Burgelman, 1995). So, at least in the absence of active incumbents who were theorized to have the ability to influence the public media, it was not surprising that the performance claims made by young and small firms, as well as the claims of reputed innovators from other industries, were popularized. Newness and smallness can be an asset as well as a liability, even in the same scenario. An interesting theoretical question implied by this observation, for organizational ecologists (Hannan & Freeman, 1977; Scott, 1993), is whether smallness and newness are *net* advantages or disadvantages when innovation is the main determinant of survival during periods of technological discontinuity.

Before summarizing, it is important to stress an observation that was made in a prior discussion. The above arguments pertain specifically to the dynamics happening at the level of analysis maintained throughout this study. At higher levels of analysis institutional partisanship was so obvious that the need for rigorous research in the specific assertions underlying the present hypotheses was obviated. Compared to the information campaigns that were *admittedly* being crafted (Cronk, 1995) by players in industries like automobile manufacturing, petrochemicals, electric power generation, etc., the institutional dynamics at the level of electrochemical innovation seemed subdued, almost moot. Great institutional forces were defending and attacking the California mandates and the concept of electric vehicles in general, but this was not the focus of this study. It is testimony to the overall validity of s-curve and Technology Cycles frameworks that they had such a great deal of explanatory ability in an institutional field which was embedded in another field so plainly characterized by sociopolitical forces.

In summary, the main points presented in this section arc as follows. As argued in the literature review, growth of the popularity of Institutional Theory (Scott, 1995) can in part be observed by noting the rapid proliferation of viewpoints concerning the legitimacy construct (Suchman, 1995). This dissertation successfully borrowed the interpretation of cognitive legitimacy as meaning overall public awareness (Aldrich & Fiol, 1994) to help dissect and analyze the cognitive legitimation of a new industry in terms of the most urgent measure of performance, and the most urgent measure of cost/price.

Adding to the proliferation of interpretations and usages of the legitimacy construct, the results of this study suggest that if cognitive legitimacy is something of a continuum (which "total public awareness" suggests), then it extends negatively as well as positively. There are important differences between cognitive non-legitimacy, positive cognitive legitimacy, and negative cognitive legitimacy.

However, applying this abstraction to any specific scenario is likely to demand some flexibility and extensions. Negative cognitive legitimacy can but does not necessarily have to negate positive cognitive legitimacy in mathematical fashion; "positive" and "negative" aspects of cognitive legitimacy reflect human values, not mathematical values. There are likely to be qualitative differences in the natures of different dimensions of cognitive legitimacy and even of specific measures of a particular dimension.

Furthermore, intuition suggests that interpretations can vary a great deal across levels of analysis. Paradoxically, negative cognitive legitimacy at one level of analysis can be interpreted as being positive cognitive legitimacy at another. As plain and straightforward as the construct might seem, then, the state of theoretical development of cognitive legitimacy is not in final form. Overall public awareness is not a simple construct.

The results of this study also implied that the observability of a competence may be associated with the relative ease by which related claims are cognitively legitimated or de-legitimated. In some scenarios, claims related to developments in firm-specific abilities to translate scientific knowledge into user functionality -- i.e., technologies -- can be relatively easy to cognitively legitimate because they are newsworthy, optimistic, and difficult to dispute. The overall legitimacy of an organization (i.e., its reputation) as well as the general legitimacy of an organization's characteristics (e.g., smallness and newness) might be communicable to or even synergistic with this dynamic. Conversely, claims related to competences that are not firm-specific, and/or are easy to comprehend and interpret by media players and their consumers, can be relatively easy to cognitively de-legitimate. In some scenarios, unobservable articles of faith may be easier to cognitively legitimate than calculations of observable "facts".

Limitations and Conclusion

This section concludes the study by summarizing the main implications discussed above, and then by offering suggestions for further research.

But before doing so, it is appropriate to acknowledge limitations of the study. The weakest aspect of the present study was its methodology. Specifically, all variables were measured categorically and frequency analysis was used to test all hypotheses. Qualitative extensions of the analysis were extensive and necessary, not merely illustrative.

First, the nominal measures used were coarse. It is not difficult to argue that industry membership/participation can be operationalized dichotomously, but it can just as easily be argued that incumbency is a metric variable; hence, it is easy to argue that operationalizing industry incumbency dichotomously threw away important data. On the other hand, the measure proved to be sufficient for exploratory purposes, and discussions indicated that a more rigorous operationalization might have distracted attention from the opportunities afforded by Morphological Analysis which only became more apparent as the study progressed. An explanation follows.

Statistical inconclusiveness of the tests of the hypotheses concerned with the relationship between industry incumbency and the fundamental categories of innovation was rooted not in the weaknesses of the operationalization of industry incumbency, but in the strength of the main tenets of the Technology Cycles literature in this scenario. Certainly, somewhere within or around the boundaries of SIC 3691 were the boundaries of the set of those U.S. firms which were primarily engaged in manufacturing Lead-Acid Storage Batteries for the automotive sector. U.S. manufacturers of storage batteries in general, and Lead-Acid Batteries in particular, were just not reported very much as developing electrochemical innovations for electric vehicles. As imperfect as SIC 3691 was as an operationalization of industry incumbency, imperfections did not distort the reality that SIC 3691 firms simply were not very active. No refinement of this operationalization came close to changing any interpretation of any finding. In fact, the consistency of this finding established footing from which to improve an understanding of the concept of industry incumbency.

Intuition suggests that when the enhancement and/or destruction of competences is at stake, a sensible way to operationalize incumbency is to measure the main competences of concern. The more competent a firm is at something, the more incumbent it is to the relevant industry. Other measures such as firm size, age, market share or volume, etc., would at best be proxies for competences. But since, theoretically, competitively advantageous competences are tacit and unobservable, operationalizing incumbency in terms of competences contains an inherent and severe range restriction. The more competent a firm is, the more difficult it is for an outsider to observe it, or to at least understand it. Therefore virtually any measure of a firm-specific competence must be a proxy. The issue is which proxy is best.

This study used Morphological Analysis to dissect electrochemical innovations by observing them to be combinations of options needed to embody necessary natural phenomena. In doing this, it dissected the product-technology competences that were being applied to the development of each innovation. Morphological measures (MD and PT) used in this dissertation were proxy measures of product-technology competences, though they were categorical measures.

The painfully obvious and very direct way to associate these categories with a metric measure is to also evaluate innovations in a critical dimension of performance. From a purely technical point of view, a firm is incumbent to a technologically-defined industry (a definition which relates phenomenological function to user functionality) to the extent that its products perform. It makes just as much sense to say that a firm will be unwilling to destroy its own ability to produce high-performing products, as it does to say that a firm will be unwilling to destroy years of investment, capital imbededness, and so forth. Saying the former, in fact, in a technical sense is just a more direct and clear way of saying the latter.

The point is manifold, but straightforward: (a) industry incumbency is a difficult construct to operationalize; (b) when the enhancement and/or destruction of competences is at stake, "industry" is intuitively associated with types of product-technology competence, and "incumbency" is intuitively associated with levels of competence; (c) since competences are theoretically unobservable, proxies must be used; (d) by categorically dissecting product technologies, Morphological Analysis also categorically dissects product-technology competences; (e) by associating morphological categories with s-curves, competences can be measured metrically.

Therefore the limitations of using Morphological Analysis are far outweighed by its potential. *This is the fundamental conclusion of this dissertation.*

It is important to understand the limitations of Morphological Analysis, however. Perhaps the most imposing is that it takes a great deal of time, patience and researcher interest to develop an analysis that produces even a simple matrix. Second, each analysis is accordingly only as good as the skill and assumptions behind it. Third, each analysis and matrix is idiosyncratic, limited to a specific problem definition, and limited to a specific level of analysis. However, these limitations are typical of the problems developing typologies, which are what morphological analyses essentially produce, and which are very common to research in Strategic Management. Fourth, analyzing product technologies only dissects product-technology competences; there are, of course, other firm-level competences of very great and often greater importance. But here, it should be recalled that Morphological Analysis is in no way limited to considering only product technologies. It is a general approach to problem-solving that is extraordinarily flexible, and is applicable to a wide range of problems, business and otherwise.

The limitations of operationalizing cognitive legitimacy as being the number of reports of advantages and disadvantages of performance and cost/price are fairly clear. First, every report in every media item was considered equally. Obviously, not every media item could have an equal effect on overall public awareness. Some readerships were large, while some were small; some constituencies were broad, while some were narrow; some items were rich and lengthy, while others were pithy and short; some had no purpose other than information dissemination, while others editorialized liberally. No attempt was made to weight the gravity of each report in each item. On the other hand, the real issue of concern in the latter four propositions was not public awareness as much as it was the possibility that the public media might be influenced by industry players. The precise issue was not actually overall public awareness, but the possibility of biased reporting.

Next, operationalizing all variables in categorical terms virtually mandated the use of frequency analysis, which is not a rigorous technique. Even strong results demand some subjective interpretation. Small samples can be particularly uninterpretable. The form of any relationship, and especially causality, is indeterminable. Low expected frequencies (and skewed distributions in general) inject the likelihood of Type II error. The test of independence (chi-square) is an approximation. Measures of Association (such as C) are relative and difficult to otherwise interpret.

These limitations would have seriously injured the present analysis had the statistical results not been so clear. That is, in most cases tests of hypotheses either rejected or failed to reject the null hypothesis by such wide margins that the above dangers were avoided to a great extent. Failure to reject the null at even alpha = .1 made the likelihood of Type II error low even in the presence of statistical bias. Where tests failed to reject the null, it could be confidently assumed that there was truly no statistical association between variables. Conversely, rejections of the null at alpha = .01, and in some cases .001, made statistical association a virtual certainty; so much so that face value interpretations were likely to be correct. In fact, the general air of the discussion seemed to become one where a mostly qualitative assessment was being corroborated by simple statistics, as opposed to an abstract discussion of a cacophony of statistics in search of a congealing rationale. The main issue became not the interpretation of each individual test (note that Measures of Association were presented but not much discussed), but interpreting the basic theoretical contradictions implied by bipolar contrasts (standardizing tables greatly facilitated such comparisons).

Interpretability was greatly enhanced, not limited, by sample size. In fact, one could argue that two thousand public media items, collected systematically and professionally over a two-year period, all addressing a fairly narrow band of all possible newsworthy events, was a very, very substantial portion of the total population of media items on the subject. It is very likely that the frequencies observed in the population sample were highly representative of the actual, total population. This helped low observed and expected frequencies, which are statistically troublesome, to be meaningful at face value. In this study, sample size was an important strength which went far towards ameliorating other worries about statistical interpretability. However, interpretations ultimately relied on comparing statistical results with a qualitative assessment of technical and symposium data. Though the sources of information used in these assessments were highly credible, interpretations were entirely subject to the skills of one individual. Several thousand pages of technical and symposium data were difficult to succinctly, no less accurately, summarize and present without some selection biases. A replication of this portion of the analysis might show differences. On the other hand, recall that one of the basic strengths of Technology Cycles studies is their richness. As such, all suffer symptoms common to qualitative research. This dissertation added rigor to a stream of largely qualitative research as much as it suffered from lack of rigor relative to some other bodies of literature.

In other words, strategy-oriented research in the evolution and revolution of technology faces trade-offs between positivistic rigor and contextual completeness. This dissertation did not resolve any associated dilemma. It added richness to what might otherwise have been an empirically rigorous oversimplification, meaningless to a technologist; it added rigor to what might have been a non-replicable and value-driven case analysis, unacceptably idiosyncratic to a strategist. More importantly, it made progress towards integrating several of the major concerns of several bodies of literature, which after much additional work could help develop a new and challenging synthesis of the strategic elements of technological change.

The main contribution of this study to the Strategic Management literature is the illumination of a view that is already established in the Management of Technology literature: technology, first and foremost, is not the result of competence -- technology is competence. One reason that this view has been slow to develop in Strategic Management research might be the very reason it is so important. Technology, as competence, is difficult to observe and is often tacit at the level of the firm. Tacitness is what affords some of its proprietary characteristics and potential for competitive advantage; meanwhile, tacitness is the characteristic which makes it difficult for many academic researchers to observe, understand, and embrace.

At any rate, if technology is competence, and if knowledge and skill are key components of competence, then technological change involves learning. Learning can be serendipitous, but it also can be conscious, goal-oriented, and pro-active. Serendipity implies probabilistic occurrence and variation-selection-retention models of technological change. To outsiders (and academic researchers are outsiders), technological change may seem to be random, unpredictable, and wholly probabilistic. Insiders -- technologists -- know that precise technological forecasting is next to impossible, and that nature has a way of stubbornly refusing to relinquish its secrets on orderly command, or at least in neat proportion to the allocation of resources. But at the same time they know that resources are very purposively allocated towards the resolution of fairly specific technological bottlenecks, at all levels of organization -- and that focused breakthroughs are not uncommon and always accidental. What can seem to be happenchance and sporadic to the outside observer is not, by far, always accidental to technologists who daily make it their professional lives to realize progress. One can choose to learn serendipitously, or one can choose to learn specific new things.

Or one can choose to learn along a trajectory and make the most of serendipitous discoveries along the way.

The gravity of these distinctions is nowhere more evident than in the path-dependency of technological choices. Success at learning in one area only invites more learning in the same area. The successful inauguration of a technological trajectory has tremendous leverage towards its entrenchment. Only when it becomes clear that performance growth along one technological trajectory is phenomenologically limited, does it become clear that if greatly superior performance is to be achieved, a new trajectory must be inaugurated at non-trivial cost, potentially on several levels of socioeconomic organization.

Furthermore, there is no necessary correspondence, or association, between the size of the "gale" on one level of analysis, and the amount of "destruction" it can cause on another level of analysis. This is not the same as saying that a modest innovation can have a great impact. Anecdotally, many people are aware of the enormous impact of innovations like the integrated circuit, the incandescent light bulb, gunpowder, the stirrup, and so forth. The point is that a strategy of rolling out successive, small discontinuities is not necessarily as conservative and risk-averse as it might seem. Small discontinuities can potentially impose huge externalities, socioeconomic disincentives so severe that an entire trajectory can be stillborn. It is sometimes possible that a more radical, destructive, different, or morphologically "distant" technological discontinuity, viewed from the product level, can be more acceptable at the socioeconomic infrastructure level. Strategists should carefully consider this irony vis-a-vis short and long-term organizational goals.

Also, some consciously intended paths of learning can be difficult enough to demand significant amounts of organization. The backyard or basement tinkerer can not be relied upon to rejuvenate every industry in the throes of such a need. Industrial metamorphosis has more than two options: complete suicide/rebirth or assassination and takeover by the unheard-of. Logically enough, industrial metamorphosis can be viewed as morphological migration -- the realignment of competences aimed at bringing new levels of product function to new or existing consumer functionalities. In less cryptic language, new industries can develop through new, synergistic alignments of existing, as well as new, firm-level and/or firm-specific competences. Backyard entrepreneurship is important, but so are inter-industry joint ventures and alliances, consortia, trade organizations, some degree of public-sector coordination, and so forth. Organizational amorphousness (at any level) is not a completely reliable structure for imposing significant, goal-oriented (non-random) morphological migration.

A final conclusion offered to strategic managers and strategic management researchers alike is that they would do well to gain an appreciation of the technological-phenomenological antecedents of the products offered by their respective industries of concern. The limitations and demands of nature are imposing and make requirements of product technologies and organizational competences. Created, or at least impermanent, realities like market segments, industry boundaries, strategic groups, and so forth, can have phenomenological underpinnings that this dissertation has only implied. The simple but important suggestion is that the limitations and opportunities of natural phenomena, when mapped, might be real, reliable, and useful maps of potential industrial change.

The main contribution of this study to the Management of Technology literature is additional confidence in the fundamental tenets of technology s-curve and Technology Cycles frameworks. Despite many complexities, virtually inextricable causal direction, and in this scenario severe sociopolitical distortions, technological progress can be understood in terms that are consistent and rigorous.

Unfortunately, and to risk a contradiction in terms, the rigor is qualitative, not quantitative. That is, the history of technological progress is roughly but almost invariably explainable by s-curve and Technology Cycle frameworks. Often, specific s-curves of actual developments can be plotted. The general dynamic is so consistent that the future can, with much confidence, be expected to display s-shaped patterns of performance growth, and the last of innumerable, inevitable and important technological discontinuities is far into the future. But specific forecasts are inherently problematic -- since the essence of innovation is doing (or creating) things that have not been done (or created) before, or metaphorically, since innovation means exploring territory that has not been explored before, one can not draw a detailed map of unknown terrain until one is at least in the process of exploration.

And exploration is a choice. It is not inevitable, at least not monolithically on a broad, comprehensive, and always perfectly rational frontier. Going in specific, challenging directions mandates organization and resource allocation; in such cases, performance growth is the direct result of technologists' effort. From the Strategic Management perspective, pure ecological models of technological progress condescend human intelligence and will. They may go far towards explaining the sociology of technological change, but offer few helpful suggestions to practicing technology strategists.

Therefore, underdeveloped areas conundrums in s-curve and Technology Cycles frameworks should not be interpreted by academic researchers as being clear signals that further theoretical development is impossible. This study, for example, has suggested that the discontinuity-ferment-dominant design-stability model of technological change is not inviolable. The present scenario seemed to be better depicted as political discontinuity-ferment-technological discontinuity/dominant design-stability. Yet s-curves still seemed to be pervasive and powerfully explanatory.

This oddity should not be dismissed as being anomalous. It might be a harbinger of things to come, as governments appreciate more and more the pros and cons of pro-active technological development from social, economic, and other points of view.

In a sense, the results of this study suggested that s-curves are solid first approximations, but that there is still much to be done about developing the theoretical basis of subsequent approximations. For example, it is important to realize that phenomenological (theoretical) limits are derived from scientific knowledge. Practical limits will very often be lower than phenomenological limits, as engineers are always likely to encounter many practical problems between the laboratory and the marketplace. This observation does not discount the validity of s-curve frameworks as they are, it just suggests that applications beyond a rudimentary understanding must consider practical as well as theoretical asymptotes. Again, it can not be overemphasized that performance growth is a direct result of human effort, made mostly (or at least most directly) by technologists. Generally speaking, performance growth is not directly caused by the passage of time, variations in market demand, or political mandate. Performance growth is the direct result of technological competence and all competences are subject to management and mismanagement.

Additionally, performance growth in one measure is not always independent of growth in other measures, and not all interactions are positively synergistic. In fact, performance trade-offs are common. Any s-curve should be appreciated as being a very focused representation of performance growth in one and only one measure and should never automatically be considered to represent a pattern of growth in overall acceptability.

Though no very specific form of the relationship was ever proposed, this study consistently implied that a main non-phenomenological variable that interacts with performance growth is cost/price. In general, it is accepted that product substitution becomes likely as product price/performance ratios become similar, though performance seems to be the more formidable element of this dynamic. Results of this study supported this view. Considering all available options and their phenomenological limitations, it seemed inevitable that storage batteries intended for use in electric vehicles, superior in performance to the dominant design, would appear. The handwriting was on the wall, so to speak, and crude but credible performance expectations were not seriously distorted between the publications written by directly-involved technologists and media professionals who surely ranged in their degrees of short-term disaffection from the issue. Performance seemed assured.

The battleground was cost/price. Cost containment and abatement was either not inevitable or relatively easy to argue, or both. The spoils of winning portended to be spectacular. Ostensibly, and regardless of ultimate performance potential, if one trajectory could be successfully dissuaded from gaining short-term popular appeal based on cost/price exorbitance, the associated delay could give the proponents of another trajectory (tacitly collusive or not) the opportunity to establish a path-dependent, though in other terms tenuous, foothold. Once a trajectory is successfully inaugurated, other factors are likely to then positively synergize and accelerate improvements in performance and cost/price in that trajectory, severely dissuading continued allocation of resources to competing trajectories, even ones that had/have the potential to be superior in most meaningful measures in the most long-term view.

The main contribution of this study to the Technological Forecasting (R&D Management) literature is the observation that the meaning of product morphology might bear extensive conceptual expansion. That is, the morphology of a product's technologies might be a boilerplate for other structures related to the product. In the most immediate sense, a product's morphology seems to be a reasonable representation of the separate technological competences needed to develop it. Additional inspection of a morphology is also likely to identify what in the Strategic Management literature are termed "core" and/or "distinctive" competences. Morphological Analysis gets into the black box of technology in a rational, systematic and replicable way, producing typologies of feasible alternatives that form distinct patterns that relate phenomenological function to user functionality, and depict technological trajectories, possible market segments, strategic groups, and industries. Inasmuch, the potential of Morphological Analysis increases as does the complexity of the product. At the same time, the technique is extremely flexible; so much so that idiosyncricity of results is an important caveat. At any rate, R&D managers have tools and insights that make them uniquely qualified to help develop not only technology strategies for practicing managers, but also the theory of technological evolution and revolution from the strategic perspective.

A contribution of this study that is of mutual benefit to both the Management of Technology and Technological Forecasting communities is an enhanced understanding of the relationship between s-curve frameworks and morphology. That is, the strengths of each help ameliorate some of the weaknesses of the other. S-curves are unidimensional and oversimplified, a weakness that becomes troublesome at high levels of analysis such as Technology Cycles. A Morphological Analysis of any complex product, however, produces a disjointed matrix of phenomenological building blocks that suggests thousands of possible combinations. With the insight that a morphological analysis can provide, s-curves can be thought of as simple representations of multi-parametric patterns of exploration. With the elegance that s-curve frameworks can provide, rough patterns of exploration can be forecast. In short, the literature indicates that exploration of a map tends to occur at or near the frontier; more distant leaps tend to be expensive, tend to be risky because of the additional uncertainties involved, and tend to be pursued by players with little "incumbency" to lose. Consequently, distant leaps tend to be aimed at combinations that have clearly superior performance and profit potentials.

The main contribution of this study to the Institutional Theory literature is the simple but important observation that cognitive legitimacy, interpreted as overall public awareness, is not nearly as simple as this definition implies. The mere awareness of the existence of something, such as an impending technological innovation, can easily be interpreted in different ways. The simple awareness of a technological innovation is likely to be intertwined with an understanding of its features; for example, how well it will perform and how much it will probably cost. There will often be a point of reference, such as a prevailing or dominant design, against which one can reasonably assert that observations of an innovation's features are either negative, by way of their relative inferiority, or positive, by way of their relative superiority. Thus not all public notoriety is necessarily advantageous, depending on the specific question at hand. Researchers should take care to consider the converse of their operationalizations of cognitive legitimacy, as full understandings of symmetries and asymmetries can wholly change interpretations. As well, academic researchers should consider the value-ladenness of their operationalizations and research questions, because academic researchers participate in the cognitive legitimation of issues and their dimensions.

Another contribution to the Institutional Theory literature is a first-known test of Aldrich & Fiol's (1994) assertions about how firms should be expected to use their ability to influence the public media to defend the legitimacy of their product technologies and attack the legitimacy of the technologies of competing firms. On this specific issue, however, results were inconclusive. A level of analysis was chosen below one that would have produced results that were already obvious. Unfortunately, at the level of analysis chosen, the predictions of the Technology Cycles literature were so overwhelmingly true that direct empirical contrasts of institutional considerations could not be established; that is, incumbents were so inactive even in developing incremental improvements to the dominant design that their hypothesized ability to disproportionately profit from legitimation/de-legitimation processes could not be determined. Furthermore, in general the public media's representation of actual industry activity seemed accurate and fair, leaving the analyst at a loss to conclude whether media campaigns were ineffective or simply non-existent.

On the other hand, there was little doubt concerning several serendipitous findings. First, from the academic researcher's point of view, it is reasonable to expect public media data to contain a bias towards newsworthy events. Second, it was important to observe that one technological trajectory clearly got a huge plurality of the overall publicity. Had the hypotheses asserted that phenomenologically-defined trajectories would be legitimized differently based on the possibility of tacit collusion, instead of the more basic incumbent-v.-non-incumbent argument, results would have been discovered more directly. In other words, the MD dichotomy was too coarse-grained a measure to get affirmative statistical results (concerning differences in legitimacy), and PT was too fine-grained a measure. It seemed that a phenomenological definition and measure of the concept "technological trajectory", based on tacit collusion and strategic group logic and literature, would have worked well.

Finally, for the sake of perspective it is important to note a simple Institutional Theory version of an interpretation that has been consistently phrased in other terms. It has been argued that because some competences are tacit and unobservable, they might be easier to legitimate than competences that are observable, imitable, and arguable in comprehensible detail. In Institutional terms, ininimitability and unobservability are akin to buffers (Scott, 1992). Technological competences might be more mythological (Meyer & Rowan, 1977) than others, making them more difficult to refute. A firm's reputation for innovation might be one of the most important organizational resources towards enhancing its ability to survive, and perhaps lead, technological discontinuities.

Implications for additional research are straightforward. Probably the most inviting area for further development is the potential that appears to be inherent in Morphological Analysis or techniques like it. The main potential of the technique lies in its ability to enter the black box of technology. Any product at any level of analysis can be dissected about the same way electrochemical devices were dissected in this study. Additionally, the technique is not limited to the analysis of product technology; nor is it limited to studying technology. It is simply a way of breaking down any problem that has definable boundaries into its most elemental dimensions (or, when considering technological innovations, phenomena), so as to allow a full consideration of each manner (option) of delivering each elemental (phenomenological) function, en route to being able to consider all possible combinations of options (designs). This study has shown that it can produce a matrix, or map, of competences, feasible and unfeasible alternatives, phenomenologically distinct categories of innovations, and phenomenologically defined technological trajectories. To the extent that these structures are valid, the technique is immediately useful to technologists and those studying technology and technological change. To the extent that these structures represent or foretell socioeconomic and technoeconomic structures, their potential to academic research has barely been implied.

A related suggestion for additional research is the need to develop competence-based views and operationalizations of industry incumbency. Static views of industry are adequately served by using extant methods and structures like SIC. But when changes of structures are at issue, prevailing views are inherently flawed and myopic. Visualizing "industry" as a set of competences, or alignments of competences, has the potential to also visualize industrial and technological evolution and revolution. Of course, competences are inherently difficult to operationalize; proxies must be used, but some are much better than others.

As such, the death-rebirth model of creative destruction may be oversimplified. Serendipitous discovery should be encouraged, of course, but many technological directions will, in the future, be made by choice and will involve new forms of private, public, and joint private and public organization. A metamorphosis/migration model might better represent choice-based dynamics of technological evolution and revolution than a winner-take-all model. Here, variation-selection-retention is not the same as metamorphosis because choice is not a main engine of change in ecological models. Metamorphosis and migration invite concepts like choice and resource allocation along intended trajectories.

S-curve and Technology Cycles frameworks have the potential to become theories and there is much room in them for further theoretical development. The multidimensionality that underlies almost any high-level s-curve can be explained morphologically; likewise, performance-based metric measures will often be calculable. Interactive and perhaps recursive models of change should be developed that consider not only multiple measures of performance, but dimensions such as development cost and price.

Though this dissertation did not delve deeply into the psychology of cognitive legitimacy, several implications and conclusions suggest the need for additional research. First, it became apparent that the importance of cognitive legitimacy in the transitions among technological paradigms and trajectories may vary a great deal by level of analysis. High levels of analysis imply much public visibility of powerful and distinctly different antagonists struggling for positions in obvious ways. Low levels of analysis imply low levels of public visibility, where antagonists are likely to differ in ways that are technologically subtle and semantically cryptic. Therefore, pro-active legitimation and de-legitimation in the public media might be difficult to accomplish at low levels of analysis. Second, cognitive legitimacy seems to have a positive side and a negative side. Especially where smear campaigns are important to a particular issue, it is important for researchers to consider the value ladenness and the converse of their operationalizations. "More" cognitive legitimacy can be a help or hindrance to the successful introduction of technological innovations.

A summary of the implications for practitioners is as follows. First, from the strategic perspective, managers should take efforts to avoid the potential myopia that extant mental structures of industries and markets might impose; aligning competences and end-user functionalities affords a fresher perspective from which to identify firms that are likely to determine the structure of future competitive space. In that vein, managers should appreciate that technology is first and foremost human-based competence, the ability to translate scientific knowledge into commercializable products; and that technologists have well-precedented tools for mapping out the present state of industrial affairs and likely paths of progress. Thinking through these pathways can lead a manager to consider strategic alternatives less draconian than those implied by the most common, intimidating interpretation of the Schumpeterian view. "Creative destruction" can, ironically, be managed somewhat incrementally, through the evolution of innovative forms of industrial organization -- joint ventures, alliances, consortia, networks, etc. From this perspective, incumbents are never necessarily doomed even in the long-term, but should self-induce careful metamorphoses of alignments of competences.

Managers need to understand the ubiquitous dynamics of s-curves and Technology Cycles. Innovation is probabilistic in the sense that detailed apportionment of resources never guarantees the accomplishment of specific goals, but the general shape of progress within phenomenological potentials is predictable. Managers should track performance growth assiduously over time, and understand that what is ultimately being tracked is learning. Hence managing performance growth is to manage learning, which is likely to be synergistic with firm-level variables like sales volume and cost.

Therefore, managers should understand that though new competitive space will take shape primarily through the delivery of performance, short-term cost problems are far from irrelevant, even if they are likely to be resolved in the long-term. Slow starts, caused in part by communicable pessimism about high costs, can allow other firms pursuing innovations of inferior performance potentials the opportunity to establish intractable trajectories, or path-dependencies. Therefore, managers should understand where their firms' innovations fit amidst developing trajectories and potential technological bandwagons. For example, a firm closely following technological developments within an increasingly popular trajectory might be in the best position to slingshot technology followship into market leadership. In this example and elsewhere, reputation for innovation is important to develop and guard.

Managers must continue to develop their understanding of non-market forces. In a broad sense, technological progress can be legislated, though the results of mandating a "push" approach are very likely to differ from the results of a "pull" approach. Personal preferences aside, managers must understand that perspectives of technological change will often vary across stakeholder groups and levels of analysis. Public forums for debate, such as a free press, are likely to show patterns of representation that, aside the issue of technical accuracy, can be interpreted in different ways. Public priroties will not always mirror the firm-specific priorities, and a tactical perspective will sometimes conflict with a strategic perspective. As well, a global view will not always be the same as a national view.

Consumers of the results of this study should carefully consider the generalizability of all interpretations and conclusions. For example, this study focused on manufactured/ assembled products. Dynamics in the service sector might differ. Similarly, process innovations can be as important as product innovations, even in the manufactured/assembled product sector. The difference between a product innovation and a process innovation is sometimes obscure, a point which can be particularly troublesome when equating technology to competence. The boundary between product and process innovations is not always clear when both result in added value to the end-user.

Also, the literature consistently shows that industry is an important moderator of strategic dynamics. The automobile industry should be appreciated as being globally critical, politically volatile, enormously visible, extremely oligopolistic, and an important part of the fabric of twentieth century, western civilization. The evolution of related industries and/or subsectors is embedded in this milieu. The evolution of many other industries will obviously be affected by other, often less extreme conditions.

All things considered, a final suggestion is a call for much more multi-disciplinary research. Strategic Management theory typically portrays itself as being a synthesis of the contributions of several bodies of literature. This dissertation does not take the position that fields like Industrial Organization, Marketing, and Administrative Behavior should contribute less to the further development of Strategic Management theory. This dissertation does take the position that the Management of Technology also be considered as being centrally important to Strategic Management research and the strategy process. This position might not be the most popular one, but in no sense is it new. At least in the economics literature, the central importance of technology and technological change to economic development and growth has been recognized since the seminal contributions of Adam Smith and David Hume, who both wrote at times when the entire industrial revolution was anything but obvious.

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APPENDIX 1

Research Scenario and Morphological Analysis

The growing concern for air quality has been an important factor towards motivating a movement to develop automobiles which do not pollute (Considine, 1994; Cronk, 1995; Fortune, 1993; Meyer, 1994; Winn, 1994; Pratt, 1992). Not surprisingly, the State of California has taken the lead in the promotion of zero-emission vehicles through legislative action. Succinctly, beginning in 1998, 2% of all new autos sold in the state by the major auto manufacturers must be zero-polluting, and the percentage grows in the out-years. If an automaker does not comply, it will be fined $5,000 for every vehicle it sells in the state. A body of 12 northeastern states, led by New York and Massachusetts, has enacted or is considering very similar statutes. Altogether, 33% of all autos sold in the United States could soon be affected by these laws.

In the foreseeable future, the only viable auto technology capable of zero-emissions is an all-electric vehicle (EV). Besides having (arguably) positive effects on the quality of air, EVs have other inherently appealing qualities: quietness, convenient home refueling, extremely low maintenance, and a reduced dependence on oil. However, they presently have drawbacks: high cost/price, short driving range, lack of public recharging infrastructure, lack of available maintenance expertise, unproven safety, and "concerns simply about new technology ... 'Legislation has forced an initial market for EVs, but creating a self-sustaining, long-term market for these vehicles requires widespread public acceptance ... Ultimately, this acceptance will depend not only on the cost and performance of the vehicles themselves, but also on the convenience of owning an EV in this gasoline-dominated society'" (Fortune, 1993, no page).

Initially, however, the main obstacles are indeed technical. At present, electric vehicles do not perform as well as gasoline-powered autos in several ways. Most experts agree that the main problem is limited range; EVs do not travel very far on one charge. This deficiency has fomented an enormous amount of attention on electric vehicle power sources. Testifying before the United States Congress, a General Motors spokesman articulated perhaps the most common perception of the problem: "I think the emphasis has to be placed on the dollars spent in the research and development of alternative battery technology. The lead-acid battery is a first step on a journey, or an evolution of electric vehicles. You have to get started; somebody has to make the beginning step to put high-volume vehicles in the marketplace ... There is a substantial amount of ongoing research that has to be done in alternative batteries" (Hearing 162, 1990; 137). Testifying before Congress several years later, a GM Vice-President rephrased the problem: "Beyond the mid-term, a 'next-generation' battery is needed that will allow electric vehicles to be a competitive alternative to gasoline-powered vehicles. These long-term technologies will require extensive scientific development at the electrochemical cell level to determine technical feasibility and commercial viability" (Hearing 28, 1993; 79).

Though these two testimonials sound very similar, from the viewpoint developed in this dissertation they are distinctly different. The most obvious difference is the long-term (i.e., more strategic) orientation of the Vice President's comments. The second difference is the phenomenological focus of the Vice President. Though the first spokesman correctly identified the most popular hardware -- in fact, he identified the dominant design (lead-acid batteries) -- the Vice President correctly identified a technology/competence in terms immediately amenable to a morphological analysis. With the words "electrochemical cell," he identified the basic group of phenomena and level of analysis that are most appropriate to a Morphological Analysis of the EV range problem.

In order to conduct a Morphological Analysis of electrochemical cells, a precise statement of the problem must first be made. In the view of technology described earlier, this means that the problem should be phrased in both functional and technical terms. Based on the above discussion, *the functional problem is to increase the distance a "battery"-powered all-electric vehicle can travel between charges.* Though this statement seems simple, it assumes the following: electrochemistry is the preferred means of converting stored energy to auto-locomotion; the vehicle is a passenger automobile; the automobile is new; the space available for battery storage is fixed (total volume, but not shape); velocity (and hence acceleration) is fixed/optimal. These assumptions are necessary in order to focus on the problem as it has been stated, for the following reasons. First, electrochemistry is not the only source of electric power that can propel an automobile, but alternative technologies seem very unlikely to develop in the time frame of concern (Hearings 1990, 1993; Winn, 1994). Second, many "alternative fuels" are extremely low-emitting but none are zero-emitting (Lawlor, 1994). Therefore, no hybridization of electrochemistry with any form of internal combustion engine is considered. Third, niche products like buses and delivery vehicles present less of a space constraint than do passenger autos. However, the theoretical and practical problems expressed earlier address mass-market commercializability. Passenger autos must be developed in order to change the automobile industry on the scale envisioned, and these vehicles are limited in available space to the extent that volume is fixed, at least to a very modest range. Finally, the range of an EV, much like the miles-per-gallon of a gasoline engine, is affected by its age and how it is used. Optimal conditions will be assumed.

Translating the functional problem into a technical/technological problem, it becomes: improve the energy density (gravimetric or volummetric) of an electrochemical cell (or "battery" of cells). This statement, as well as the following discussion, is derived from an understanding of the basic natural laws that govern electrochemistry and electrochemical cells. (Brant, 1994; Bockris & Khan, 1993; Encyclopedia Britannica, 1988; Hackleman, 1992;).

"Energy density (or gravimetric energy density)... also known as specific energy ... is the amount of power available from a battery for a certain length of time (under optimal conditions) measured in watt-hours per pound of battery weight. It translates directly to the range performance your EV can get out of its batteries ... Volummetric energy density ... is energy density measured in watt-hours per gallon or watt-hours per cubic foot" (Brant, 1994; 230-231).

Fortunately, a basic knowledge of electricity is all that is required to derive the phenomenological parameters that govern the energy density of an electrochemical cell. First, Ohm's Law holds that in any electric circuit, voltage or electromotive force (E) is equal to amperes or current (I) times the total internal and external resistance (R) in the circuit: $E=IR$. The power of a device is expressed in watts, which equals the product of voltage and current: $P=VI$.

Since the numerator of either volummetric or gravimetric energy density is watt-hours, and since a watt is volts times amps, one watt-hour is equivalent to one volt-amp-hour. This means that volts and amps must phenomenologically "happen" in an electrochemical cell, and therefore are two of its most fundamental parameters.

In a cell, some kind of anode (or negative electrode) must be available that, because of its electrical charge at the molecular level, has a surplus of electrons that it "wants to" release. Some kind of cathode (or positive electrode) must be available that, because of its electrical charge at the molecular level, is deficient in electrons and "wants to" accept them. The former process, because it originally involved molecules containing oxygen, is termed oxidation; the latter is termed reduction. The combination of a specific anode and a specific cathode is called an electrochemical cell -- the *differential* of the electrical states between the two electrodes determines the voltage of the device (the higher the differential, the higher the voltage). Therefore, oxidation and reduction are so dynamically interrelated that either is essentially meaningless without the other. Morphologically, voltage arises from combined oxidation-reduction (Redox) phenomena and each specific couple has an inherently different voltage. Therefore, Redox is a phenomenological parameter, where the options are identifiable by the labels which many observers will find familiar: lead-acid, nickel-cadmium, sodium-sulfur, and so forth.

Next, amperes (current) must be considered. As the term "current" implies, amperes is an expression of electron flow. Now one of the aforementioned assumptions becomes very important. In an electrochemical device, rate and duration of flow are very much inversely related; at a constant velocity, however, rate of flow is constant and maximizing range is to maximize the duration of flow. This means that the time component of the battery's "capacity," or amp-hours, must be maximized.

At constant velocity, amp-hours is a function of the number of available electrons. The number of available electrons is directly proportional to the amounts of reacting materials. In the case described above, where the anode and the cathode contain the reacting materials, this means that amp-hours are limited by the amounts of materials in the anode or in the cathode. For any electrochemical couple, this amount is absolutely limited by the size (volume) of the device, which has been assumed to be fixed. Other than making incremental improvements to the device's internal geometry and architecture which would make better use of available space, one way to improve amp-hours, and one that is phenomenologically different from the case described above, is to choose materials such that the electrodes and the reacting materials are not one and the same. In this way, the reacting materials can be stored outside the device in vehicle space not consumed by the device itself, then transported into the device as a type of consumable "fuel" (for all practical purposes, this also means that the reacting materials must be either liquid or gaseous as they are transported into the device). This describes most "fuel cells," which are phenomenologically very similar to the more commonly heard expression "batteries." (Fuel cells are sometimes referred to as "reverse batteries" or "reverse electrolysis" devices, but the basic underlying phenomenon is, nevertheless, oxidation-reduction). In sum, the commonality of (a) the materials undergoing oxidation-reduction and (b) the materials that constitute the electrodes, is a phenomenological parameter that affects amp-hours. Two distinct options that have very different limitations are "common" and "separate."

Also, electric currents must travel through a medium. In an electrochemical device the medium is called the electrolyte (a medium is also required outside the device in order to have a complete circuit, but this has been assumed). In some devices, the electrolyte is chemically reactive; in others, it is inert. In all devices the electrolyte provides unavoidable internal resistance. However, the performance characteristics of specific electrolytes are dynamically interrelated with the chemical properties of the electrochemical couple. That is, electrolytes are chosen to optimize oxidation-reduction, and phenomenological differences are driven by the need to accommodate the choice of electrode materials. In the same sense that O-R was considered to be one phenomenological parameter, the dynamic participation of the electrolyte is considered part of it as well. This is true of both batteries and fuel cells, even though fuel cells' nomenclatures typically identify the composition of the electrolyte, rather than the electrodes.

To be complete, Brant (1994) listed the following factors as affecting a device's capacity: area or physical size of the plates (electrodes), weight and amount of materials in plates, number of plates and types of separators, quantity and specific gravity of the electrolyte, age, condition, temperature, voltage limit, and discharge rate. Most of these factors have either been accounted for in the above discussions, or have been fixed by assumption, but some deserve additional explanation.

Most importantly, many construction features/choices affect the size of the surface area of the chemical reactions that produce the current, which determines the rate of current flow, which defines a crucial parameter called specific power or power density. This phenomenon translates to speed and acceleration. As discussed above, while there is a crucial trade-off between specific density and specific power, the range problem demands a focus on specific energy. Current EV technologies provide adequate acceleration and speed characteristics; it is range that is critically inadequate. In principal, power density is an important parameter, but as it applies to this specific problem, conditions that determine it can be assumed. Furthermore, it should be noted that innovations that affect the surface area of the cell reactants are by definition incremental improvements to existing morphs. While these are no doubt important, at the present level of analysis, they do not constitute phenomenologically different options.

As well, a battery's weight is crucial. This is a function of its size and the density of the constituent materials. However, size is assumed as fixed (which obviates the denominator of volummetric energy density), and the density of materials is driven by the more urgent choice of choosing materials based on their material (voltage) properties (which obviates the denominator of gravimetric energy density). Thus while size and density are important, there are no phenomenologically different "options" that are not already automatic in other choices.

Similarly, thermal efficiency affects power, so it affects range. Thermal efficiency is principally a matter of power that is lost due to the unavoidable conversion of some chemical energy into heat instead of electricity. This is a function of the total resistance in the circuit. Since speed and acceleration are fixed, and other external conditions are not considered variables, external load is fixed. Internal resistance is largely a function of the device's construction and type/amount of electrolyte and other materials used. Again, though there are some important trade-offs here, there are no phenomenologically different "options" that are not automatic in other choices.

Specific energy is also a function of the simple temperature of the device. Cold devices do not flow as readily as warm devices, as a rule, and in fact some devices need fairly precise conditions. More specifically, some devices will not operate at all under normal driving conditions; they need to be maintained at hundreds of degrees to operate at all. Fundamentally, then, considering that operating conditions have been assumed as optimal, the two basic options concerning temperature are whether it will be controlled, or not. The performance differential between these two options is so dramatic, it is essentially a "go/no-go" determination.

Finally, "range extenders" should be considered. Many technologies (such as aerodynamics, tire chemistry, etc). are undergoing rapid rates of development in order to extend the range of EVs. But maintaining a focus on the problem as it has been stated, they do not affect a device's specific energy while in the state of discharge. However, it is possible to partly recharge some types of devices even while they are functioning, by capturing and feeding back energy losses (due to friction, thermal losses, etc.), reconverted to electricity. However, devices that consume non-regenerative fuel can not be recharged this way. For the sake of simplicity, it will be assumed that any device that can be regenerated while in discharge, will be engineered as such. Therefore where regeneration is a phenomenological parameter, basic options are feasible/present and infeasible/absent. Essentially, this groups primary (non-rechargeable) batteries with most types of fuel cells (which operate in the manner described earlier) as one phenomenological type of option, and secondary (rechargeable) batteries with other possibilities (such as rechargeable fuel cells) as the other type of option; a division which is otherwise not obvious. Rechargeability while in operation is an interesting parameter, and the phenomenologically distinct options directly affect range.

(At this point it should be noted that whether a device can be "refueled" by either recharging or replacing its "fuel," are two options of a parameter that is not of concern to the problem as it has been stated. From another interpretation of the range problem, a very important issue is the lack of public infrastructure whereby EV owners can conveniently either recharge their batteries or physically replace a consummable fuel. However, the focus of the problem at hand is the range that a vehicle can travel on a single amount of fuel, in which case the method of refueling or replacement is not a range constraint. In fact, even a long-life primary battery is an entirely feasible solution, theoretically speaking).

In all the above, the more sophisticated reader will be familiar with the many ways that electrochemical cells might be altered and possibly improved in terms of the selection of materials other than those discussed (separators, connectors, casings, etc.), manufacturing technique, the internal architecture of the device, and so forth. In the morphological view of the problem as it has been stated at the level of analysis of concern, however, these are either process improvements or incremental improvements to existing morphs. The above discussion leads to the following morphological matrix.

Table A.1. Morphological Matrix of Electrochemical Devices.

Parameter	*Option*	*Option*	*Option*
Redox	Lead-Acid	NiCad	Other
Commonality	Combined	Separate	
Temperature	No Control	Control	
Regeneration	Feasible	Unfeasible	

APPENDIX 2

CODING INSTRUCTIONS

1.) Before you are 25 articles that all pertain to the advent of the electric automobile. read one article at a time, completing all of the following instructions for each article before proceeding to the next.

2.) As you read an article, mark it up liberally as you look for the following information. First, identify any/all of the devices listed on the attached list of "Power Types." Second, identify and mark the manufacturer(s) of each device. Third, mark/note any statement that infers how (a) the price/cost, and or (b) the range (distance it allows a vehicle to travel on one charge) characteristics of the device COMPARES with the price/cost and range characteristics of its "alternatives" (see below).

3. On the coding sheet, indicate the number of the article (handwritten on each article) under "NUMBER". Write the name of each device under "POWRTYPE" and use the attached sheet to also code its "MD" and "PT". Write the name of the manufacturer(s) under "POWRMFG" and refer to the attached sheet to code the manufacturer's incumbency: if the name appears on the list, mark a "1" under "INC"; otherwise mark a "0". use as many lines on the coding sheet as necessary to account for each POWRTYPE and POWRMFG (but don't code one POWRTYPE more than once per article unless there is more than one manufacturer).

4. Refer again to your impressions about relative cost and range characteristics, and consider this basic question for each POWRTYPE you identified: if POWRTYPE is a type of Lead-Acid battery, how does it compare to any other POWRTYPE that is NOT Lead-Acid; if POWRTYPE IS NOT Lead-Acid, how does it compare to Lead-Acid? More specifically, for each POWRTYPE identified, subject it's description to the following questions. Any time an answer is "yes", mark a "1" in the appropriate column on the coding sheet. Otherwise just leave spaces blank.

Present range: does the article say that POWRTYPE
    provides a better (higher) range than its alternative, NOW? (NOWBETR)
    provides a worse (shorter) range than its alternative, NOW? (NOWWORS)
Future range: does the article say that POWRTYPE
    WILL provide a better range than its alternative, IN THE FUTURE? (THENBETR)
    WILL provide a worse range than its alternative, IN THE FUTURE? (THENWORS)
Present Cost/Price: does the article say that POWRTYPE
    is cheaper than its alternative, NOW? (NOWCHEAP)
    is more expensive than its alternative, NOW? (NOWEXP)
Future Cost/Price: does the article say that POWRTYPE
    WILL be cheaper than its alternative, IN THE FUTURE? (THENCHEP)
    WILL be more expensive than its alternative, IN THE FUTURE? (THENEXP)

Remember that you are comparing Lead-Acid Batteries to any other POWRTYPE, and any other POWRTYPE to Lead-Acid Batteries. Consider "Lead Acid" and "anything else" as two alternatives. Do not compare non-Lead Acid POWRTYPEs to each other.

Exhibit 2. Sample Coding Sheet (Data Contrived).

CASE	NUMBER	POWRTYPE	MD	PT	PWRMFG	INC	NOWBETR	THENWORS	NOWCHEAP	THENEXP	NOWWORSE	THENBETR	NOWEXP	THENCHEP
1	1001	Lead-Acid	0		Duracell	0	1							
2	1002	Lead-Acid	0		Eveready	0	1		1					
3	1003	NiCad	1	1	Electricar	1								
4	1003	Zinc Air	2		SAFT	1					1	1	1	
5	1003	Nickel Iron	1	1	ABCo	1								
6	1004	NIMH	1	1	Ovonic	1					1			
7	1005	Molten F.C.	3		Fuelsinc	1								
8	1006	Sodium Sulf	2		Duetsch	1					1	1	1	
9	1006	Zinc Chl	1	1	Delco	0						1		1
10	1007	PbSO4	0		Gates	0	1	1	1					
etc.														

VITA

Robert N. McGrath received a Bachelor of Science degree from the United States Air Force Academy in 1977, majoring in Organizational Behavior while completing a core engineering curriculum. From 1977 to 1982 he served as an Air Force officer, supervising the maintenance of F-4, F-15, and F-16 fighter aircraft, and supervising the decontamination of unexploded devices on bombing and gunnery ranges. He was awarded a Master of Social Science (Public Administration) degree from the University of Northern Colorado in 1980. From 1982 to 1986 he was employed by Texas Instruments, Inc. (Lewisville, Tx.) where he performed Logistics Engineering and Program Management tasks on several developing systems which later became famous during the 1990 Gulf War. His division earned the prestigious Malcolm Baldridge National Quality Award during this time. From 1986 to 1990 he earned an MBA in Management (Xavier University, Ohio) and worked as a Systems Engineer and Program Manager for both General Electric Aircraft Engines and the Lockheed Aeronautical Systems Company at the 18,000-employee GE facility in Cincinnati, the largest industrial employer and exporter in Ohio. Since 1991 he has been pursuing a doctoral degree in Business Administration (Strategic Management) at Louisiana State University in Baton Rouge.

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Title of Dissertation: Discontinuous Technological Change and Institutional Legitimacy: A Morphological Perspective

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