POLICY DESIGN FOR COMPETITIVE RETAIL ELECTRIC INSTITUTIONS: ARTIFICIAL INTELLIGENCE REPRESENTATIONS FOR A COMMON PROPERTY RESOURCE APPROACH

by

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Dedication

In Loving Memory of My Grandfather,
Damodar Gopal Pandit
(29 November 1911 - 10 April 1998)

माझे आजोबा, ति. कै. दामोदर गोपाळ पंडित
तथा
परमपूज्य नानांच्या
पवित्र स्मृतीस समर्पण

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ABSTRACT

POLICY DESIGN FOR COMPETITIVE RETAIL ELECTRIC INSTITUTIONS: ARTIFICIAL INTELLIGENCE REPRESENTATIONS FOR A COMMON PROPERTY RESOURCE APPROACH

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The U.S. electricity industry is being restructured to increase competition. Although existing policies may lead to efficient wholesale institutions, designing policies for the retail level is more complex because of intricate interactions between individuals and quasi-monopolistic institutions. It is argued that Hirshman's ideas of "exit" and "voice" (Hirshman, 1970) provide powerful abstractions for design of retail institutions. While competition is a known mechanism of "exit," a novel design of the "voice" mechanism is demonstrated through an artificial intelligence (AI) based software process model.

The process model of "voice" in retail institutions is designed within the economic context of electricity distribution - a common property resource (CPR), characterized by technological uncertainty and path-dependency. First, it is argued that participant feedback (voice) has to be used effectively to manage the CPR. Further, it is noted that the decision process, of using participant feedback (voice) to incrementally manage uncertainty and path-dependencies, is non-monotonic because it requires the decision makers to often retract previously made assumptions and decisions.

An AI based process model of "voice" is developed using an assumption-based truth maintenance system. The model can emulate the non-monotonic decision making process and therefore assist in decision support. Such a systematic framework is flexible, consistent, and easily reorganized as assumptions change. It can provide an effective, formal "voice" mechanism to the retail customers and improve institutional performance.

CHAPTER 1

INTRODUCTION

Policy research in restructuring of the U.S. electricity industry is in vogue again (Anon, 1998a). This time, all eyes are on the new wholesale commodity markets for kilowatt-hours (kWhr) particularly, but not limited to, California. The new electricity commodity market will be emulated soon in other states. The excitement is not surprising because the electricity market is very large. In 1995, annual sales of electricity in the U.S. were $190 billion as compared to other traded commodities such as natural gas ($75 Bn), cattle ($30 Bn), sugar ($7 Bn) and silver (less than $1 Bn). The only other competitive markets of similar scale are in telecommunications ($160 Bn) and automobiles ($150 Bn).

The California situation is proof that electric utilities in the U.S. are changing rapidly (O'Reilly, 1997) in both scale and scope of operations. By the middle of 1997, seven bills were before the U.S. Congress (Anon, 1997) containing significant changes to support market restructuring of electric utilities. All bills attempt to show their benefits to consumers. In March 1998, the Clinton administration put forth its proposal to promote deregulation of electricity. Meanwhile, so many novel technological configurations are envisioned, e.g., (Levin, 1997), that many analysts are calling the wholesale competitive market reforms and profit potential to be nothing less than a revolution (http://www.hemnet.com/deregulation).

In the midst of the euphoria, this research takes a pause and looks at policy design issues that are relevant for serving retail consumers of the electric industry. The sections below introduce the research scope, describe the research theme, discuss why this research is relevant, and present an overview of the research approach and a roadmap to this thesis.

Scope

Order No. 888 by the Federal Energy Regulatory Commission (FERC) set in motion the changes evident in the states today. FERC's Order No. 888 formally laid the groundwork for several consequent changes including the establishment of a competitive commodity market for bulk electricity[1], i.e., at the wholesale level. With belief in competition as the mechanism for performance improvement of institutions, a number of the states are adding further to the FERC's stipulations by setting up schemes which allow retail end use customers to directly access the wholesale market.

There is a fuzzy boundary between the wholesale and retail levels; this is true in the electricity industry as well. Hence, a number of institutions are evolving in response to the changes. This research looks at design and requirements of institutions, which provide an interface between the wholesale and retail markets for electricity. In particular, this research formulates a formal methodological abstraction for representing

[1] Although FERC did not specifically require the establishment of a commodity market per se.

institutional structures at the retail-wholesale interface. Models based on such powerful abstractions can be used to design institutions and improve organizational performance.

Theme

This research effort makes a distinction between policy analysis and policy design. Whereas policy analysis[2] uses numerous tools to evaluate policy options, this research attempts to create a policy design. To clearly define what is meant by policy design, this research adopts the (Simon, 1994, Ch. 6) view that policy is a social artifact, created to pursue a particular goal or purpose. In this case, it means that policy is the interface between the substance and organization of the electric industry and the context in which it operates. Policy design then is based on "the pristine positivist position of the irreducibility of 'ought' to 'is'" (Simon, 1994, p. 8) and therefore, designers are concerned with how a policy artifact ought to be engineered to function in a particular context.

Designing policy for the electric industry for implementation on a societal scale calls for "modesty and restraint in setting the design objectives and drastic simplification of the real-world situation in representing it for purposes of the design process" (Simon, 1994, p. 163). The major issues to be addressed in the policy design process include choosing an appropriate method of representation (conceptualization) of the design problem, data availability, the nature of retail customers, time requirements for the

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[2] The policy analysis field can be subdivided into two components (Lerner & Lasswell, 1951). The "knowledge of" component is akin to social sciences generally, in that it seeks to understand and explain the process of policy making. On the other hand, the "knowledge for" component includes studies that evaluate and compare alternative policy options (Bobrow & Dryzek, 1987).

design, and the process of design without a clear specification of the final product. The design is the basis of an incremental process that is not yet complete. This means that the design must be internally consistent, flexible, and easily and rapidly "re-engineerable." For retail electric institutions, this design research is warranted by the requirement that the policy artifact will function within a specific context. The necessary (but not sufficient) condition is that the research is relevant to the complex economic setting while not violating the physical laws that govern production and distribution of electricity.

Relevance

This research in policy design is relevant because it shares the main goal of the restructuring legislation in the U.S. and elsewhere, i.e., retail customers must be served better. In addition, the current public policy debate is rife with the interaction of interested parties including consumer organizations (http://www.ilsr.org), state legislatures (http://www.naseo.org), and industries (http://www.eei.org) and opposition from public power (http://www.APPAnet.org) and rural cooperatives (http://www.nreca.org).

This research is also relevant because it looks beyond the interest group policy positions that promote either market competition at the most decentralized level (Crandall & Ellig, 1997) or public ownership in a centralized vertically integrated utility (Kwoka, 1996). Rather it rests on the observation that a rich variety of institutions involving states, organizations, and individuals can lead to modern industrial organizational transformation (Evans, 1995). This research focuses on how to design institutions to meet specific policy goals and improve organizational performance within those institutions.

Further, this research is relevant because it is framed within realistic and conservative assumptions about the future. For example, this research assumes that although rapid technological changes will affect institutional structures, the inherent capital intensive nature of energy investments reduces the pace of technological change (Rosenberg, 1994). Therefore, the emphasis here is on considering the impact of only a few key technological trends which cause incremental and commercially observable change. That is, impacts of futuristic technologies such as magneto-hydrodynamics and nuclear fusion are not considered. In addition, this research does not rely on strong assumptions about either the abundance (Simon, 1981) or scarcity (Lovins, 1977) of natural resources.

From the methodological perspective, this research is relevant because it aims to create a powerful representative model of the decision making process used by retail-wholesale institutions. A powerful representation enables us to readily simulate realistic scenarios within the context of different institutional designs and, in turn, improve organizational performance - a key step in the policy design process (Simon, 1994, pp. 164-169). While there may be alternative methods for representing the decision making process, the designer must choose between them to model specific feature(s) of interest. However, this research argues that specific artificial intelligence based representations are necessary for modeling key features of high performance retail electric institutions.

Approach

There are several general approaches for designing retail institutions. Three branches of economics, micro-economics (Baumol, 1977), institutional economics (Williamson & Winter, 1993), and evolutionary economics (Nelson & Winter, 1982), are the most prevalent approaches. The relevance and limitations of these approaches to this study are briefly discussed below, leading to a rationale for the use of atypical economic concepts of "exit" and "voice" (Hirshman, 1970) for the design of retail electric institutions.

- Micro-economics is founded mainly on the principle of economic rationality (Becker, 1962) and is applied in the form of cost-benefit analysis (Mishan, 1988). As such, micro-economic principles prescribe the formation of markets with accurate pricing methods, which is accepted here.
- To explain the vertical integration and horizontal diversification of industry, institutional economists provide a means of accounting for transactions costs (Williamson, 1985) and agency costs (Jensen & Meckling, 1973) which are not always reflected accurately in market price signals. Such costs may arise from several sources, such as government regulation. The general prescription, that these frictional costs have to be minimized in institutional design, is also accepted in this research.
- Using a Schumpeterian basis, evolutionary economists provide explanations about the role of innovation in competitive markets (Rosenberg, 1994). The general prescription, that forces of innovation have to be unimpeded, also is accepted in

this research.

All three approaches prescribe competition as the main mechanism of performance improvement of institutions. In addition, all three approaches recognize that individual behavior is not perfectly rational; it is characterized by "bounded rationality" (Simon, 1994, Ch. 2) and "quasi-rationality" (Thaler, 1992). Further, all three approaches agree that an efficient market is the effective institutional mechanism for implementing competition. Finally, the three approaches have not provided successful prescriptions for designing institutions, which can address problems that arise in the following situations.

1. Situations where a fully competitive market has never been in place, and is unlikely to be in place. Such situations are common in infrastructure related industries and in using shared resources, such as common property resources (Ostrom, 1990).
2. Situations in which there may be socially undesirable and externalized side effects even when competition is nearly rampant, as in the laissez-faire era during the industrial revolution in the 19th century.

Consequently, all three approaches prescribe in essence that competition should be tempered with "appropriate" mechanisms of regulation and cooperation, as exemplified by the property rights approach (North, 1990). However, competition is always viewed in all three approaches as an effective mechanism, where all competing institutions, which do not serve their customers, should fail and simply disappear.

However, institutions do not simply disappear and, in fact, they often change - for better or worse. By recognizing the scope for institutions to recuperate from poor performance (Hirshman, 1970), it becomes possible to view competition as one mechanism for inducing performance improvement in institutions, where customers exercise the "exit" option, i.e., of switching suppliers who do not provide satisfactory service. Another mechanism, which induces performance improvement, is "voice" where the customers' feedback is used by the institution in a constructive manner to provide satisfactory service. The prescription adopted in this research is that a combination of "exit" and "voice" mechanisms is necessary for designing institutions, which can induce recuperative performance improvement.

Roadmap

To research the design of institutions for retail consumers, it is important to place the problem in its historical context. A summary of relevant historical changes is presented in general chronological order in Chapter 2. In particular, salient features which relate to the genesis and status of the shift from regulation to competition are noted. Specifically, key impacts of legislative changes on retail customers are presented within a broad institutional context (Hirshman, 1970).

The policy framework in this study allows us to look at different ways in which the vertically integrated electric utility is being decentralized into its constituent parts. Chapter 3 examines if the framework of decentralization can assist in the design of new institutions that continue to evolve at the retail-wholesale interface. The decentralization framework appears to be effective in explaining the behavior of institutions and consequently, may be useful in testing the efficacy of hypothetical institutional structures. However, the focus of this dissertation is on design of policy rather than analysis and testing of policy alternatives. Therefore, there is little use of explanatory tools, such as hypothesis testing, in general for this research and as a consequence, the decentralization framework is found to be of minimal use in this prescriptive study.

Specifically, the key role of new institutions in providing common property resources (CPR) (Ostrom, Gardner, & Walker, 1994) is analyzed in Chapter 4. Within this policy framework, the analysis shows that retail-wholesale CPR institutions evolve continually and incrementally (Ostrom, 1992), and therefore, policy design must model the incremental process characterized by path-dependence.

Chapter 5 assesses alternative methods to model the path-dependence in retail-wholesale institutions. The review of alternative formal methods is developed into a rationale for selection of a formalism for modeling retail-wholesale institutions based on an artificial intelligence based representation of non-monotonic logic (Filman, 1988).

Chapter 6 presents a simple case study to illustrate the use of the formalism and describes other cases where the non-monotonic representations may be applicable in the new retail-wholesale electric institutions. Chapter 7 presents the conclusions.

Appendix A provides a brief discussion of how artificial intelligence tools can be used to represent institutions as rules with a well defined grammar (Crawford & Ostrom, 1994). Appendix B describes the commercial modeling tool used to model non-monotonic processes and to implement the case study described in Chapter 6. Appendix

C presents screen shots of a demonstration of the implemented case study. A roadmap of the thesis is presented in Table 1 below.

Table 1 : A Thesis Roadmap

Chapter	Issue	Argument	Reference
2	What does the electric utility history tell us?	Institutions can maintain good performance by providing formal mechanisms for exit (competition) and voice (constructive dissent)	(Hirshman, 1970)
3	Is decentralization the design approach?	No. Decentralization can be useful for explanation, not for prescription.	
4	Why are electric institutions difficult to design? What are their main features?	Diverse institutions are needed to provide a common property resource (CPR) like electricity. Their main feature is path-dependence (non-monotonicity) in decision processes.	(Ostrom et al., 1994), (Ostrom, Schroeder, & Wynne, 1993)
5	How can CPRs be represented for policy design?	Use artificial intelligence (AI) methods, with assumption-based truth maintenance systems to model non-monotonic decision processes.	(Filman, 1988), (Simon, 1994)
6	Examples?	ESCO management Coordinated Multilateral trading Dynamic Scheduling & Dispatch	
7	Conclusions	And recommendations	
App. A	Modeling institutions	How to use AI to represent rules which describe institutional behavior	
App. B	Modeling tool	A customized description of KEE™	
App. C	ESCO Demo	Screen by screen printouts	

CHAPTER 2

BACKGROUND OF ELECTRIC RE-REGULATION

To appreciate the complex history of the electric industry in the U.S., it is important to track the evolution of several key actors and institutions. It is also important to recognize at the outset that the electric industry has never seen a perfectly competitive market. In fact, the sections below are based on the observation that five well known forms of market imperfections have been influential in the electric industry, assuring that Pareto optimality could not be achieved or maintained.

1. When there are a small number of buyers or sellers, e.g., monopolistic competition, the actions of individual actors becomes important and the "invisible" hand[3] of the market no longer provides correct pricing signals.
2. When there are externalities, e.g., social costs of "debilitating competition" in the 1920s and the environmental costs of air pollution, the prices are not correct (Dorfman & Dorfman, 1972).
3. When there are significant transaction costs, actors tend to reorganize in order to minimize them. For example, regulated utilities were compelled to become vertically integrated to reduce transaction costs (Williamson, 1985).

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[3] In fact, the invisible hand metaphor for the market has been re-coined by some economists as the "many hands" metaphor (Chandler, 1990).

4. When collective non-market goods are produced, e.g., infrastructure, it may not be possible to exclude free-riders or to tap an unlimited resource and increase production indefinitely to meet demand (Ostrom, 1990).
5. When production costs are indivisible and demand is finely divisible, an "empty core" may lead to collusion and inefficient allocation (Telser, 1994), e.g., peak power production in response to daily and seasonal variation in demand.

As the electric utility industry has never been in a fully competitive environment, the fortunes of individual firms are not necessarily determined by changes in comparative advantage alone. In fact, the performance of institutions does deteriorate and recuperate. Therefore, it is useful to make the electric industry's historical review within the broad context (Hirshman, 1970) that:

> *Under any economic, social, or political system, individuals, business firms, and organizations in general are subject to lapses from efficient, rational, law-abiding, virtuous, or otherwise functional behavior.* [italics added] (p. 1)

The organizational lapses are often seen as repairable deterioration in performance in the quality of the product or service provided[4]. Responses to such organizational decay appear in the form of *exit* or *voice* or both, followed by the management's search for recovery. Exit reflects the clear response of customers who stop buying the firm's products or leave the organization. On the other hand, voice response refers to the

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[4] Contrast with conventional economic interpretation of deterioration within a fully competitive system, where recovery from any lapse is not essential as it is caused only by basic shifts in comparative advantage.

customers expressing their dissatisfaction directly or through a greater authority, such as politics, or through a general protest. The historical review below provides a view of the retail customers' relationship with the electric utility in the form of their responses via exit or voice or both.

The first section below discusses the roles of the various actors and refers to how they relate to the retail consumer. The subsequent section describes salient features of Orders 888 and 889 issued by the Federal Energy Regulatory Commission (FERC) in 1996 which opened the U.S. electric industry to wholesale competition. The next section shows how the nature of the regulated industry would not be complete without a description of the role of the states. Comparisons from electric industries in several countries around the world is outlined in the following section; it demonstrates how the U.S. restructuring plans continue to influence and be influenced by experiences abroad. The next section enumerates debates that are going on vis-à-vis the evolution of retail markets for electricity in the U.S. The final section presents a summary of relevant features of the re-regulation process for the retail customer.

U.S. Electricity: A Brief History

For the retail consumer today, the U.S. electric utility appears to have been a monopoly forever. In fact, the electric utilities were a highly competitive set of merchant plants early in the 20th century, particularly in New York, operating in a regulatory vacuum. In this environment of uncontrolled competition, customers were free to change electricity providers quite readily if they were dissatisfied with the service that they were receiving. The result was a highly disorganized and unreliable infrastructure of electricity. Using the argument that the municipal utilities were providing unreliable service in an environment of "debilitating competition," state laws began to emerge in recognition of the limits of the competition mechanism. There also is reason to believe local corruption and growing market power of the emerging privately owned utilities (Colton & Sheehan, 1989) set the basis for a Federal Trade Commission inquiry (voice) into "fraud, deceit, misrepresentation, dishonest, breach of trust and oppression" (Brennan et al., 1996).

The Rate-of-regulation Era

The public outcry (voice) was recognized by President Franklin Roosevelt's New Dealers. In 1935, it was enacted as the Public Utility Holding Company Act (PUHCA) to rectify the situation by limiting the utilities to regional entities and to a vertically integrated organizational structure. Meanwhile, regulatory mechanisms for wholesale trading of electricity were placed under the Federal Power Act (FPA) of 1935.

Born out the New Deal regulations, the independently owned utilities (IOUs) saw few structural policy changes until the seventies. There were two main developments in the years characterized by rate-of-return regulation (or cost-of-service), both based on the public's "voice." First, concern (voice) precipitated by the serious blackout in the northeast in 1965 led to the formation of the North American Electric Reliability Council (NERC) to ensure that the national grid system was maintained to provide reliable service. To participate in the power pool by NERC's standards, the utilities had to cede some operational controls to state controlled public utilities councils (PUCs). The NERC continues to play a vital role in the restructuring process today. The second development was the meteoric rise of the nuclear industry after World War II which appeared to show the potential for generating electricity that was "too cheap to meter", followed by its rapid downfall after the recognition (voice) of serious safety and waste disposal issues (Cassedy & Grossman, 1990).

Large blocks of power also were generated and provided on a regional basis by federal power agencies such as the Tennessee Valley Authority (TVA) and the Bonneville Power Administration (BPA). Further, many smaller scale regional cooperative utilities and public power (municipal) companies owned and operated local distribution systems to service niche retail markets in specific regions. Finally, remote areas were placed on the grid by rural cooperatives, set up with the intervention of the federal Rural Electrification Administration (REA). Under the assumption of public representation (availability of the voice mechanism), the municipals and rural co-ops were exempted from state regulation.

Under the PUCs, the utilities were subject to rate-of-return regulation (Kahn, 1993) which provided little incentive to the utilities (an effective voice mechanism) to improve their performance. The rates were regulated by state (PUCs) at both retail and wholesale levels. On the other hand, some state regulators tried to overcome the deficiencies in rate-of-return regulation by adopting other retail pricing schemes, such as two-part tariffs, price-cap regulation, shared-savings or sliding-scale regulation, and benchmark or yardstick regulation. However, fueled by postwar wealth and complacency, the public had no way to exit from the monopoly power of the utilities and used little voice against the complex web of regulations until the 70's. The complacency may have been due to the abundance of low cost residential retail electric power which, in turn, was cross subsidized by large institutional and non-residential customers. This all came to an end with the oil driven energy crisis in the early seventies and then again in the late seventies.

The PURPA Years

In 1979, the Public Utilities Regulatory Policy Act (PURPA) was enacted in some measure as a response to the oil crisis, which set the policy agenda in the decade. At a time when nuclear plants were on the decline due to environmental and safety concerns, PURPA promoted development of non-utility generators (NUGs) who were not constrained to use fuels specified by the FERC. The NUGs consisted of independent power producers (IPPs) and other qualified facilities (QFs) to utilize previously untapped sources of energy (Devine et al., 1987) like industrial cogeneration[5]. The cogeneration alternative in particular provided an exit mechanism for large industrial customers to leave the local utility based spatial monopolies.

Meanwhile, PURPA supporters also tried to use regulatory methods to bring about competitive structural change in the industry and in particular, decentralization of off-grid power generation applications using renewable energy sources (Brown, 1983). However, the exit mechanisms were ineffective in the face of "lazy monopolies"

(Hirshman, 1970, p. 59) because such competition only "*comforts and bolsters* it by unburdening it of its more troublesome customers."[6] Examples of the ineffectiveness of the exit mechanism under PURPA, are net metering, time-of-use rates, and green pricing.

- For those customers with the capability of generating electricity, e.g., solar PV, gas gensets, etc., net metering can be used to sell excess electricity to the utility. During such times, the meter runs backward and therefore, the customer receives a net bill. The scheme is attractive to the consumer-producer because it is simple. There is no contentious computation of avoided cost or complex rate structures. Sixteen states have laws on net metering (Wan, 1996) for small power projects of less than 100 KW capacity. However, there are onerous conditions for making a reliable interconnection with the grid to supply power on an as-available basis (http://www.eren.doe.gov/consumerinfo/refbriefs/ja7.html), even if the costs of interconnection continue to fall (Udall, 1998). The utility's response to this form of exit by a consumer continues to be nonchalant – perhaps satisfied with weaning off a critical, demanding, and potentially disgruntled consumer.
- In some cases, exit by consumers is used constructively as an indicator to improve the product. When a consumer exits because the time-of-use rates are high, an

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[5] Simultaneous efficient generation of thermal and electrical energy to match demand.

[6] (Hirshman, 1970) notes "…it could define a whole class of economic structures where a tight monopoly would be preferable, within the framework of the 'slack' or 'fallible' economy, to competition." (p. 47)

aggressive utility will try to improve the rate structure. On the other hand, a utility with the attitude of a 'lazy monopolist' will be content in letting the customer go. Such attitude is common in organizations where incompetent or lazy personnel comfort and bolster such exits and prefer to charge the remaining complacent customers for the cost of their service[7]. In a similar manner, green pricing poses a challenge that can be picked up enthusiastically by the aggressive and competent utility. On the other hand, incompetent, lazy, and mediocre utilities condone their inability by not meeting the challenge and continuing instead to capitalize on the complacency or loyalty of consumers who choose to remain.

For some time in the 80's, mainly because of industrial cogeneration, PURPA appeared effective because almost 40 percent of new generating capacity was implemented by IPPs and QFs. However, the exit mechanism used by industry also was not fully effective for two reasons. First, utilities worked to reduce real competition by generating intricate difficulties in the interpretation of key aspects of PURPA, specifically with respect to the "avoided cost"[8] that the utilities had to pay the IPPs and QFs for electricity (Moskovitz, 1992). Second, under the rate-of-return regulation,

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[7] (Hirshman, 1970) notes more examples of how a (lazy) monopoly can be comforted by competition by noting "Those who hold power in the lazy monopoly may actually have an interest in *creating* some limited opportunities for exit on the part of those whose voice might be uncomfortable." (p. 60)

[8] In particular, the issue revolved around the avoided cost of power consideration, which was to be paid by the utilities to the NUGs. In principle, the avoided cost of power is simply the marginal cost that the utility would have had to pay to generate the power that it was forced to accept from the NUG. In practice, the computation was controversial partly because the "empty core" (Telser, 1994) formed by indivisible costs and finely divisible demand was skillfully used by the utilities to their advantage.

utilities could afford to be complacent knowing fully well that a significant portion of the income stream was allocated to them. In fact, the loss of quality customers was often welcomed as a means of letting go of the most vocal and hard to please customers.

Competition in the EPAct

Spurred by a growing complaints (voice) of regulatory inefficiencies caused by such governmental "internalities" (Wolf, 1988), structural change in the electric utilities began with the Energy Policy Act (EPAct) in 1992. The EPAct was the last of a series of laws passed by three consecutive Republican administrations as they sought to transfer ownership, control, and management of industry from government regulations to competitive markets[9]. The primary outgrowth of the EPAct was the growth of exempt wholesale generators (EWGs) who were IPPs owned by utilities or other companies across state borders.

By introducing competition, the EPAct aims to provide customers greater choice of suppliers and therefore, the ability to exit from one supplier and join another. The EPAct's target of obtaining an optimal mix of voice and exit needed to maintain a higher organizational performance is an elusive but noteworthy goal. "In order to retain their ability to fight deterioration those organizations that rely primarily on one of the two reaction mechanisms need an occasional injection of the other." (Hirshman, 1970, p. 126)

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[9] Despite initial complacency (Kash & Rycroft, 1984), the Reagan and Bush administrations dismantled regulatory structures in the airline, telecommunications, natural gas, and electric industry.

FERC Orders 888 and 889

Under the Democratic Clinton administration's Department of Energy (DoE), the Federal Energy Regulatory Commission (FERC) issued Order No. 888 (FERC888, 1996) to implement the EPAct. The FERC Orders 888 and 889 issued in 1996 are also referred to as the Mega-NOPR[10].

Order 888 refers to the regulation itself and Order 889 describes OASIS, an Internet based Open Access Same-Time Information System. OASIS was implemented to support Order 888 and in turn, enabled both generators and large consumers reserve transmission capacity on existing transmission lines to transport bulk power (http://www.stern.nyu.edu/~pdg1/oasis.html). As such, the discussion in this study refers mainly to Order 888.

Of importance to this study are Sections I (Introduction/Summary), III (Background), and IV (Discussion) of Order 888. While Section III presents the regulatory context of the Mega-NOPR, Sections I and IV provide several substantive opinions of concern to the retail consumer.

First, the Mega-NOPR summarizes the main contribution of Order 888 regarding wholesale transmission access (FERC888, 1996, Section I).

"(The Commission) requires all public utilities that own, control or operate facilities used for transmitting electric energy in interstate commerce to file open access non-discriminatory transmission tariffs that contain minimum

[10] A very large Notice of Proposed Regulation (NOPR).

terms and conditions of non-discriminatory service; to take transmission service (including ancillary services) for their own new wholesale sales and purchases of electric energy under the open access tariffs."

The Mega-NOPR did not generically provide for market-based generation rates for wholesale electricity. However, it allowed suppliers wishing to sell at market rates to demonstrate that there was no dominance (market power) on a case by case basis. This ruling provided states and NERC regions the basis to apply for schemes by which a market for electricity could be set up in the respective region.

The Mega-NOPR also discusses the scope of the rule which limits its applicability to the retail customer (FERC888, 1996, Section I).

"The Rule clarifies the Commission's interpretation of the Federal/state jurisdictional boundaries over transmission and local distribution. While we affirm our conclusion that this Commission has exclusive jurisdiction over the rates, terms, and conditions of unbundled retail transmission in interstate commerce by public utilities, we nevertheless recognize the very legitimate concerns of state regulatory authorities as they contemplate direct retail access or other state restructuring plans. Accordingly, we specify circumstances under which we will give deference to state recommendations. Although jurisdictional boundaries may shift as a result of restructuring programs in wholesale and retail markets, we do not believe this will change fundamental state regulatory authorities, including authority to regulate the vast majority of generation asset costs, the siting of generation and transmission facilities, the decisions regarding retail service territories. We intend to be respectful of state objectives so long as they do not balkanize interstate transmission of power or conflict with our interstate open access policies."

Changes at the State Level

It is noteworthy that very little of the federal historical context above shed any light on the delivery of electricity to the retail consumer. Most retail services were under state jurisdictions and implemented at local levels through distribution service organizations managed by the utility companies, with the exception of rural cooperatives and publicly owned utilities. Prior to the Mega-NOPR, the experiences at the state PUC level in retail rate-setting schemes and those of cooperative and municipal utilities was the only guideline for retail consumers. In essence, there was no exit mechanism and the voice mechanism was ineffective. After the Mega-NOPR, discussion about retail service has lead to a rush to provide competitive direct access. Not surprisingly, different states have responded to the challenge of competitive markets in different ways. The most important direction for the retail consumers is the availability of exit through direct access.

In direct access, individual retail customers can choose their own electricity supplier, just as one can choose a long distance telephone company. Presumably, a large percentage of retail customers will shop for the least expensive supplier of electricity. On the other hand, like the long distance phone companies, electricity suppliers will solicit the "best" customers by offering a myriad of pricing schemes while reducing production costs by efficient generation or purchase of energy from other suppliers. Suppliers around the nation have been gearing up to use arbitrage opportunities in the evolving electricity futures market (http://www.nymex.com). Further, suppliers are combining their electricity (Gellings, 1994) with options to buy other goods, e.g., security systems, so that retail customers with direct access will develop loyalty toward their energy brand.

In particular, California and Massachusetts continue to move rapidly toward deregulation at the retail level with 17 other states poised to begin direct access programs within the next 2 to 3 years. While most of the discussion on the potential for market power centered around the allocation of transmission rights for wholesale power, and FERC continued to develop mergers and acquisitions policies based on Order No. 888, several states began pilot programs as shown in Table 2.

While the states continue to show progress by introducing competition (exit) at various levels, the details of the competition mechanisms vary significantly from state to state. Rules of power trading, entry and exit, and other operational subtleties often can allow other mechanisms of industrial organization, such as cooperation, mergers and acquisitions (M&A), and regulation to influence the nature and effectiveness of competition. In fact, FERC Order 888 (Section IV.A.4) refers to the relevance of monitoring and enforcement of a competitive environment vis-à-vis M&A as a key concern (voice) in the antitrust aspects of the EPAct. Regulations imposed for the protection of environmental quality also exemplify public concern (voice) about the industry. In effect, antitrust, environmental regulations, and other concerns imposed by the public (voice) on the market clearly demonstrate that competition (exit) is not the sole mechanism at play in the restructuring of the wholesale electric industry.

At the retail level, FERC has delegated authority to the states and therefore, the voice mechanisms which complement competition (exit), imposed by direct access schemes, will vary considerably. Therefore, it is important to note that the generalized presentation in Table 2 does not completely reflect the status of issues at the retail level.

Table 2 : Status of Electric Industry Restructuring in the States

State	Legislation	Regulation	Pilot Program
Arizona		✓	
California	✓	✓	✓
Colorado	Proposed		
Delaware		Proposed	
Georgia		Proposed	
Idaho	Proposed		✓
Illinois	✓		✓
Kansas	Proposed		
Louisiana		Proposed	
Maine	✓	✓	
Maryland		✓	
Massachusetts	✓	✓	✓
Michigan	Proposed	✓	✓
Missouri	Proposed		✓
Montana	✓	✓	✓
Nevada	✓	✓	
New Hampshire	✓	✓	✓
New Jersey	Proposed		
New Mexico			✓
New York	Proposed	✓	✓
Oklahoma	✓		
Oregon	Proposed		
Pennsylvania	✓	✓	✓
Rhode Island	✓	✓	
Vermont	Proposed	✓	

Note: Adapted from http://www.sel.com. In the table ✓ indicates that a state implemented the legislation, regulation, or pilot program. A blank indicates that the state has neither proposed nor implemented the legislation, regulation, or pilot program.

Preliminary results from a study of the political economy of state restructuring plans (Ando & Palmer, 1998) makes the following initial generalizations.

1. Legislators are moving faster from the consideration stage to the decision stage in states with high prices relative to neighbors.
2. Pressure from environmental constituencies slows down legislative transition from consideration to decision stage.
3. Regulators in states with high prices appear to become more responsive to pressure from consumers at later stages.
4. Regulators also appear to be responding to pressure from industrial customers and low price utilities to make a final decision in favor of retail competition.
5. Appointed PUCs appear to move slower than elected PUCs to a final decision.
6. In general, interest groups whose interests coincide with efficiency-enhancing policies appear to prevail.
7. High prices and stranded costs[11] push legislators & regulators toward competition.
8. Regulators are responsive to in-state variation in price while legislators are not.
9. Access to profitable export markets also has positive effect on decision to consider or adopt competition.
10. Inter-state externalities do not affect decisions.
11. The right[12] states appear to be on the map.

However, the scenarios are not as simple as they may appear. For example, Figure 1 below from a study of comparative estimates of retail prices to rural customers in

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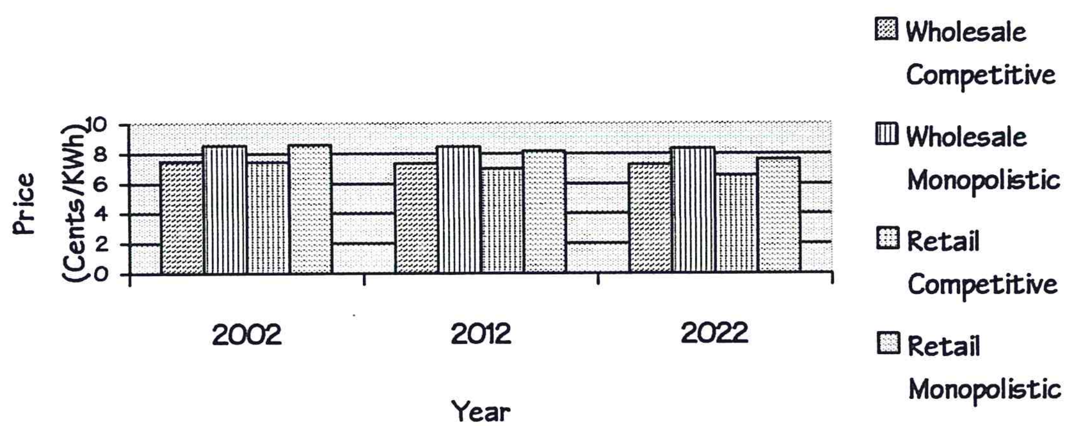
[11] Stranded costs, i.e., prior investments made by the utilities, are not addressed in this research.

[12] The states advanced in direct access legislation also feature more prominently in the development of demand side management (DSM), energy efficiency (EE) and comprehensive building codes.

Wisconsin (Glyer & Herrera, 1998) shows that the way in which competition and market power interact will have a significant impact on retail prices. Market power could be exercised by a wholesale aggregator or by the local distribution system monopoly to reduce the effectiveness of exit mechanism. To make competition (exit) effective, i.e., to curb market power in Figure 1 at the retail level, a formal complementary voice mechanism is necessary. There is little discussion of a formal voice mechanism to complement competition (exit) at the retail level.

Figure 1: Projections of Rural Electricity Prices in Wisconsin



Source: (Glyer & Herrera, 1998)

International Experience

Almost in tandem during the past twenty years (MacAvoy, 1995 Autumn), the utilities in the United Kingdom undertook a rapid deregulation and privatization program under the Thatcher government (Vickers & Yarrow, 1995), and started to replace regulation by competition in other parts of Europe (McGowan, 1993).

A number of countries have undergone the process of deregulation of their electricity industries over the past decade or so. In all cases, the systems implemented are actually quite different than in the U.S. mainly because the utilities were originally state owned. Therefore, in most cases, privatization of the state owned entities was a critical issue and one can only draw from the experiences some partial anecdotes for the U.S[13].

In the UK, in the early 90s, significant portions of the government owned industry was divested into private hands and economic regulation was imposed at the national level. Generation was privatized. Regional electricity distribution companies and a national grid company managed the wires business. A central pool managed the trading of electricity. The national independent regulatory agency set a cap on certain prices based on the formula[14] (RPI - X) where RPI is the percentage rate of change of the retail price index and X is an adjustment factor to reflect the productivity improvement in the industry. The X factor was meant to provide a performance based incentive and a voice mechanism for customers. Instead, the UK experience shows that performance based regulation specifically designed to the rule of "competitive order" decayed into a rule of "ordered competition." By September 1998, competition in the UK is planned to be at all retail levels.

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[13] By contrast, By 1994, the IOUs still maintained 76% of the total generation capacity. On the other hand, the publicly owned utilities, the rural cooperatives, and the federal utilities maintained 14%, 8% and 2% respectively of the total generation capacity in the nation.

[14] The formula was designed to overcome the poor performance record of cost-of-service regulation experience in the U.S.

In Australia, regulators and utilities have moved at different paces in different states, with a structure similar to that of the UK. Restructuring at the retail levels is planned to be implemented by 2000 AD. Generators and suppliers will transact via a pool and vesting contracts are used as hedges against variable pool prices.

In Norway, full retail competition has existed since 1991. However, because 99.8 percent of Norway's generation is hydroelectric, it is unique and not very instructive.

Many developing countries also are trying to deregulate their power industries to attract foreign investment for fueling economic growth. However, financing energy projects is difficult mostly because of a lack of credible local capital market and therefore novel financial strategies have to be employed [Hagler Bailly, 1996 #56]. Further, given the recent experience of Far East Asian countries vis-à-vis large amounts of foreign direct investment and the power outages caused by an incomplete market design in New Zealand are evidence of the need to proceed cautiosly.

Current Debates

With regard to retail consumers, several lively debates have been held on Capitol Hill in 1997[15]. While most agree that wholesale competition with direct access will lead to lower prices for the retail consumer, the need for competition in generation at the retail level is not well established.

The ongoing debate about whether competition should be introduced at the retail level

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[15] For example, see the hearings on Senator Frank Murakowski's (R-AK) Bill S. 483 at http://www.senate.gov/comm/energy/general/competit2.html.

mainly revolves around the role of public power utilities and rural electric cooperatives. Most cooperatives, municipals, and public power utilities oppose the potential competition by direct access at the retail level, but support competition at the wholesale level. The explanation is simple to understand: their regional monopolies will be threatened by the exit mechanism created by competition from power marketers, i.e., larger wholesalers who are in essence utilities without assets. Public power proponents also note that the roles and responsibilities of actors in retail distribution systems have to be clearly defined first before restructuring at the retail level – and that is no small task.

Summary

While the era of "debilitating competition" exposes some of the limits of competition (exit), the poor performance of lazy monopolies since the New Deal shows the limits of regulation (voice). FERC's Order 888 provides competition (exit) at the wholesale level and promotes it at the retail level. States are trying to provide direct access as a means of providing exit at the retail level. With antitrust-based mergers and acquisition policies and regulations for environmental protection and ancillary services, there are some mechanisms in place so that public concern (voice) can be expressed at the wholesale level. At the retail level, the states have jurisdiction and a variety of exit and voice mechanisms are likely to coexist. There is little discussion about formal, complementary mechanisms of voice for the retail consumers once competition (exit) is made available.

CHAPTER 3

POLICY FRAMEWORK: DECENTRALIZATION

The previous chapter showed that although FERC Order 888 regulations are forcing competition (exit) and regulations (voice) on the wholesale electric industry. Further, at the retail level, state direct access plans are forcing competition (exit) in the electric industry, but at that level there is no clear set of diverse mechanisms to implement voice. The main reason is FERC's position that the retail market is largely the jurisdiction of state governments, which in effect, decentralized the regulatory and management responsibilities of the retail aspects of the electric industry.

Decentralization is being implemented in varying degrees by the states by separating the vertically integrated electric utility (Della Valle, 1997) via functional (unbundling), structural (restructuring), operational (deregulation), and corporate (divestiture) decoupling, leading to the creation of a complex set of new actors and entities[16].

Decentralization implies a wide variety of policy prescriptions to different people. Due to the widely varying performance of institutions that have adopted these policies and other forms of decentralization, such as deconcentration, devolution, delegation, and

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[16] This research does *not* look at structural or corporate separation. Structural decentralization means delegation of regulation to the states. Corporate separation, addressed in the FERC's mergers and acquisition policy, is the focus of strategy management research (Teece, 1992).

privatization, it is important to recognize that decentralization is not a panacea (Ostrom et al., 1993, Ch. 8). Specifically, it is noteworthy that "Although some experimental decentralization projects have involved temporary shifts of substantial joint authority to local-level officials and to citizens involved in a project, most have done little more than transfer personnel from headquarter offices to field locations. If information obtained in the field is not taken more seriously than it was previously, the transfer is unlikely to substantially affect any of the intermediate costs involved in either construction or maintenance of a large-scale irrigation[17] system. Thus, the performance of administratively decentralized agencies is likely to be similar to that of centralized agencies." (Ostrom et al., 1993, pp. 174-175)

The sections below describe the new actors[18] created at the wholesale level by the decentralization process in the form of functional unbundling and operational deregulation. The summary discusses the reasons why decentralization alone is inadequate for policy design for institutions to better serve their retail customers.

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[17] There are several parallels between energy and other infrastructure networks (Crandall & Ellig, 1997) and irrigation (Ostrom et al., 1993). Also, convergence of various utility networks is facilitating the information management using geographic information system, wide area networks, etc.

[18] To understand a complex industrial organization (Jacquemin, 1991), including the electricity industry, one can look at the whole system or its parts. To develop policy prescriptions for complex organizations, the reductionist research approach used in this study is based on the observation that "In the face of complexity an in-principle reductionist may at the same time be a pragmatic holist." (Simon, 1994, p. 195).

Functional Unbundling

Under FERC's Order 888, utilities have to separate the vertically integrated structure into three independent organizations, i.e., generation, transmission, and distribution[19]. Per Order 888, the generation component is intended to be a competitive company with equal and fair access to the transmission system as all other competing generation companies (FERC888, 1996, Section IV).

> We conclude that functional unbundling of wholesale services is necessary to implement non-discriminatory open access transmission and that corporate unbundling should not now be required. As we explained in the NOPR, functional unbundling means three things:
>
> A public utility must take transmission services (including ancillary services) for all of its new wholesale sales and purchases of energy under the same tariff of general applicability as do others;
>
> A public utility must state separate rates for wholesale generation, transmission, and ancillary services;
>
> A public utility must rely on the same electronic information network that its transmission customers rely on to obtain information about its transmission system when buying or selling power.

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[19] Order 888 left the definition and regulation of distribution companies with the states.

The sections below describe the new actors and institutions created by functional unbundling of the production process into generation, transmission, and distribution. The last section describes new actors and institutions created by decentralization to directly interface with and serve retail consumption using the unbundled production process.

Generation: Gas and Electric Convergence

The functional unbundling of generation services has increased the competition in industry. Particularly well positioned is the natural gas industry, which already sells over 25% of its supply to the electric industry, to handle the technical and financial problems. The threat of exit posed by industrial and commercial customers can itself be an effective mechanism to get better rates negotiated with the existing generator.

As a technical alternative, gas provides a preferred inexpensive, clean, and abundant fuel, which naturally offers the potential to steadily replace aging nuclear units with equivalent capacity. Several types of gas based generators have started entering the competitive wholesale market (Wolk, 1995), including heavy frame gas turbine plants, aero-derivative gas turbines, distributed generation, gas re-powering coal and nuclear units, and integration with gasification and fuel cells.

As a financial alternative, gas fired plants can benefit from arbitrage opportunities in gas supplies, they also can provide power to customers without needing a long-term contract with the utility. The risk of price fluctuations can be managed much more skillfully by hedging in the thriving futures markets for natural gas and the evolving electricity futures markets. Three new actors have gained prominence since FERC Order 888 to provide the unbundled generation function: merchant facilities, municipal utilities, and distributed utilities.

Merchant Facilities

Based on the investor's ability to raise capital and market the services, merchant facilities provide the first evidence of competition fostered by functional unbundling. The numbers of merchant plants have increased significantly over the past few years and provide wholesale supply. Except in a bilateral trading arrangement, there is usually no interaction between the merchant plant and the retail consumer.

Municipal Utilities

Access to the transmission grid enabled by EPAct of 1992 and by FERC's Order 888 initially sparked an interest in the evolution of municipal electric utilities. It was expected that municipalities served at retail prices by IOUs would form utilities of their own and buy power from the wholesale market. Over the past few years, the process of municipalization has shown that retail customers can form groups, even in strategic sections of cities, to buy electricity at wholesale rates. Municipalization may take several forms, including power production, operation of the distribution system, aggregation of demand, and annexation of utility customers. Examples to date show (Morgan, 1996) that efforts to municipalize most often arise from the retail customers' desire to reduce rates and not by the customers' preference for public power *per se*. It is expected that interest in municipals will reduce when direct access becomes available by retail wheeling[20]. But case studies show that the threat of municipalization at least enables customers to get the most out of the IOUs and other sources.

Distributed Utilities

It is conceivable that other specialized generation entities may serve market niches also. For example, communities may be able to place peaking units which can supply directly electricity during times of peak usage and when the rates are typically higher than baseload rates. In addition to the peak shaving function, distributed utilities can generate even baseload power and sell it to the grid. It also is possible to envision gas based distributed generation units providing ancillary services in specific applications (Goldstein, 1996). In all such niche and localized applications, a dispersed generation system may not have to generate at high voltages or pay for transmission charges.

An in-depth study in the market penetration of distributed utilities was conducted by the Electric Power Research Institute (Hamm, Graves, Taylor, Iannucci, & Pupp, 1995). The summary results presented in Figure 2 show that distributed generation can provide probably 10% and up to 25% of the new generation capacity by the year 2010 AD.

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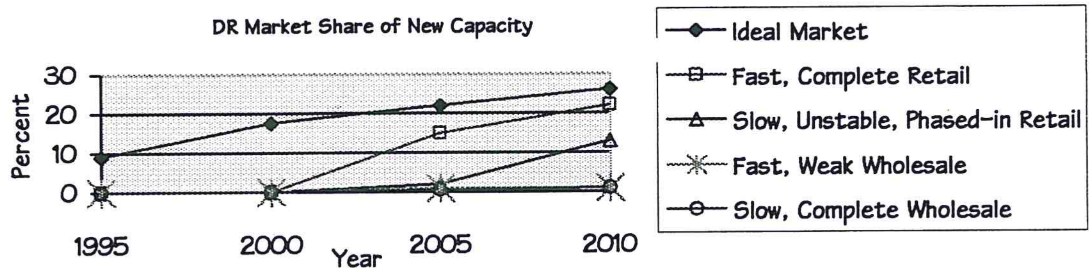
[20] Check the status of state wheeling programs - http://www.nreca.org/news/retailwheel/ret_wh_sum.htm

Figure 2 : Distributed Resource Penetration at or Near Customer Site



Source: (Hamm et al., 1995, p. 6-2)

Transmission: TRANSCOs

Transmission companies are likely to remain as regulated monopolies. Therefore, to the retail customer, there is minimal interaction with the TRANSCO except through a voice mechanism. The TRANSCO is responsible for moving electricity from the point of generation to the distribution substation. Often, the generators step up the voltage between 69 and 750 KV (~2000 amps) at the downstream end of the generator transformer breaker which connects to the generation substation. Electricity then flows over transmission lines, often running over several states (and therefore under FERC jurisdiction) to the distribution substation. The voltage is reduced between 4 and 34.5 KV and sent to radial feeders on the distribution system. The FERC has deferred to the states' judgement regarding the exact definition of demarcation between transmission and distribution systems.

Coordination of the transmission system is critical and the NERC provides stringent requirements that TRANSCOs have to fulfill to meet the technical and operational obligations. NERC has established guidelines for ten regions throughout North

America. Further, it has divided the regions into control areas which are relatively isolated from each other. NERC routinely sets performance goals for the control areas, such as ancillary service requirements, depending on their past performance, generator characteristics, interconnections with other control areas and other local considerations.

This study will refer to TRANSCOs only as references, i.e., for lessons learned, when appropriate and maintain focus at the retail distribution level.

Distribution: DISCOs for "Wires"

Distribution companies also are regulated monopolies, but they interface directly with the retail customer. DISCOs take the power from TRANSCOs at the distribution transformer between 4 and 34.5 KV and send it over the radial feeders to the end users. For residential end users, the power is stepped down further to a single-phase 110 to 220 volt and 100 to 250 amp circuit. FERC notes that the following criteria regarding distribution assets are met.

- Local distribution facilities are normally in close proximity to retail customers
- Local distribution facilities are primarily radial in character
- Power flows into local distribution system; it rarely, if ever, flows out
- When power enters into a local distribution system, it is not reconsigned or transported on to some other market
- Power entering a local distribution system is consumed in a comparatively restricted geographical area

- Meters are based at the transmission/local distribution interface to measure flows into local distribution system
- Local distribution voltage will be of reduced voltage

It is conceivable that the DISCOs could provide a number of retail customer services such as hourly metering of some customers and customer classes, automated meter reading and telemetry systems, registration of meters and customers, data collection and aggregation systems and procedures. In addition, the DISCO has to perform a number of functions requiring the development of complex operating procedures for monitoring interactions over the distribution system. At a minimum, these include:

- Transmission and distribution use of system agreements
- Distributor and aggregator agreements
- Data collection, aggregation, and security protocols and procedures
- Unbundled tariffs for distribution, transmission, and customer service providers
- Settlement procedures, creditworthiness agreements, and other transaction contracts
- Standards on metering, customer service, billing, and dispute resolution.

The customer service functions including metering, billing, and account maintenance are high value items and power marketers, aggregators, and brokers are lobbying to keep all the functions in the competitive market and not with the DISCO by default. Although decisions regarding the relative scope of activities of the power marketers and brokers and the DISCOs will be set on a state-by-state basis, the key issue for the retail customer is the following. If the DISCO provides the service, performance based regulation is likely to be developed as a voice mechanism. On the other hand, if the power marketers and brokers provide the service, competitive forces will be allowed to reward or penalize performance. For the retail customer, it is therefore important to be able to judge the performance of the DISCO in performing this monopolistic function. At this time, the rule of thumb available states that in general (Brown, 1997) 4.5% of the energy system losses are attributable to the distribution system whereas transmission systems and transformers are responsible for 3% and 1% loss respectively.

On one hand, NERC does not keep performance criteria for distribution systems[21] as it does for maintaining the reliability of the transmission system. On the other hand, traditionally the utilities have managed the DISCO functions and there are little data about performance measures for DISCOs. In general, there are four mechanisms of establishing performance measures for regulating distribution systems.

- Rate case (cost of service) versus formula based rates
- Regulated price performance standards
- Price Cap regulation (Makholm & Quinn, 1997)
- Non-price performance standards based on measures of safety, reliability, customer service satisfaction, and provision of universal service.

[21] This is unfortunate because DISCOs represent a large industry with over $50 billion in revenues per year.

It is important to note that although competition has been favored generally as an effective mechanism over the past decade, the case of DISCOs may be different and a vertically integrated structure may be more efficient (Kwoka, 1996).

Power Pools, Regions, and Control Areas

To evaluate initially if the NERC regions follow any pattern, a simple plot was drawn of the ln(size of control area) against ln(rank of control area size) using data from NERC. The chart was drawn along with data provided (Krugman, 1997) to assess if Zipf's rank-size law is obeyed by the data points.

Figure 3 : Generation Size Diversity

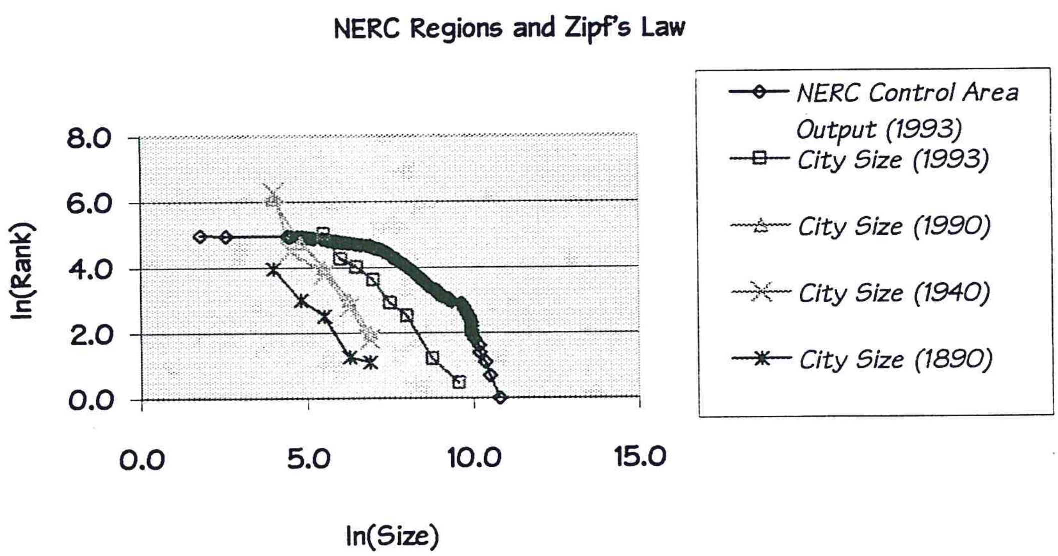


Figure 3 presents the data and shows that the data generally have the same slope of approximately –1 over a large portion of the data. It will be an extrapolation to assert that for the most part (from the largest region to approximately 1000 MW capacity), the (user exclusion). Table 3 depicts various types of public-private institutions in terms of their ability to exclude users (who cannot pay) and prevent non-rival consumption of goods. The table also provides examples of goods and services involved in the production and delivery of wholesale electrical energy.

Table 3 : Classification of Goods and Services and Electric Industry Equivalents

Exclusion	Subtractibility: Low	Subtractibility: High
Difficult	Public Goods (System Operation)	Common-Pool Resources (Transmission & Distribution)
Easy	Toll Goods (Power Trade Market)	Private Goods (Electrical Energy)

Source: Adapted from (Ostrom et al., 1994, p. 7)

All four classifications of goods and services in Table 3 are involved in the generation and delivery of electricity as explained below.

- Generally, market arrangements are effective in delivering private goods, which are excludable and allow for subtractible use and consumption. For example, by using appropriate rate structures, it is easy to exclude people (who do not agree to the payment)[31] from using electrical energy. Also, when one consumes electrical energy for any end use, e.g. air conditioning, the energy cannot be used by anyone else.

- Government services are typically designed to supply public goods, which are costly to exclude from free-riders or to prevent from joint consumption. For example, to ensure the safety and reliability of the electrical system, the key system operation tasks, especially of scheduling and dispatching power, are for everyone's benefit. FERC's Order 888 encourages states who apply to set up electricity markets to set up a non-profit Independent System Operator (ISO) and prove that it will not allow for exercise of market power by its participants.
- When exclusion is not feasible (users cannot be denied access), but where joint use is not possible, governments and private parties develop many specific mechanisms to use common pool resources. For example, the transmission and distribution system for delivering power needs to be managed so that fair and equal access to the constrained bandwidth of the lines is ensured. Order 889 provides for a computer based auction mechanism for allocation of the transmission system bandwidth to the bidders. The variety of CPR pricing mechanisms is evident in the different approaches to transmission pricing (Oren, Spiller, Varaiya, & Wu, 1994; Schweppe, Caramains, Tabors, & Bohn, 1988).

- Finally, when it is feasible to exclude users but infeasible to prevent joint use or consumption, market mechanisms can be supported by government services to provide toll goods. In the electric industry after FERC's Order 888, the most visible institution delivering toll goods are the power trade exchanges, being set up in California and several other states. The trading mechanisms are essentially algorithms (Domowitz, 1991 June) which allow scheduling coordinators to match electrical demand with generators and suppliers for a fee.

The performance of different institutional structures varies for each of the class of goods and services. There is no unique design and as described above, the electricity industry is composed of several classes of institutions to meet the needs of different goods and services produced. (Sioshansi, 1997) shows a comparison between different institutional arrangements in the U.S. and abroad. Of relevance in this research are the classes of goods and services for which it is inherently difficult to find an exit mechanism for the retail customer, i.e., public goods and common pool resources (CPRs).

From a retail customer's view, while FERC's Order 888 provides an exit mechanism for the transmission function – a common pool resource (CPR) through wholesale competition; it leaves the distribution related policy making role to the states. By delegating to the states, FERC accepts the diversity of institutions that may emerge. For example, at the wholesale level, the FERC has shown a clear preference for centralized

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[31] Improvements in metering and telecommunications will probably make it even easier to exclude non-

but independent system operators (ISOs). Consequently, while some states like California have allowed competition between different[32] power trade exchanges, others such as the Pennsylvania, New Jersey, Maryland (PJM) power pool has not encouraged the practice. Therefore, as policy issues at the retail and distribution levels are not resolved at the federal level, the states will evaluate some important experiments and observations from case studies elsewhere. Exemplary studies are described below.

In general, for the retail customer, the DISCO will be operated as a regulated monopoly and the customer exit is possible through the mechanism of direct access. Past experience with direct access mechanisms are evident in smaller systems, such as Norway, the United Kingdom, Australia, and New Zealand. In all cases, while there was clear benefit for the wholesale customer, it was unclear whether the retail customer saw significant benefit.

The state of California formally started providing direct access to retail customers on 31 March 1998 only to find the most vocal industrial promoter, ENRON[33], stopped offering retail products despite a well funded state and industry customer education campaign. One of the major reason for ENRON's withdrawal from the retail market was the retail customers did not find the prospect of switching power marketers (like switching long distance telephone companies) to be appealing (Anon, 1998b). In Norway, where direct access has been available for several years, there appears little

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payers in the future.

[32] See the Automated Power Exchange web site at http://www.energy-exchange.com/.

[33] ENRON – originally a gas trading company based in Houston, Texas

excitement among retail customers to actively participate in changing power marketing companies.

Although it is too early to assess completely the performance of the direct access mechanism, it is becoming clear that retail customers may not perceive mere switching of power marketers to offer "real choice" and to be an effective exit mechanism[34]. To evaluate alternative exit mechanisms for retail customers, it is important to analyze the functions performed in a CPR situation at the distribution level.

Functional Decomposition of Distribution as a CPR

A CPR problem typically involves a set of individuals who make repeated decisions and use a resource over and over again (Ostrom, 1992). As such, there are two classes of actors in a CPR: the producers and the providers. While providers are responsible for creating and maintaining the resource, producers withdraw units from the resource during the production process. Conceptually, while provision problems are related to the *stock* of the CPR, production problems are related to the *flow* of the CPR (Ostrom et al., 1994). The sections below describe the provision and production functions of the CPR at the distribution level.

Provision

Most provision situations are time-dependent, i.e., the choices made by producers at time *t* depend on the choices made previously at times *t-1, t-2,* ... and so on. In effect,

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[34] This phenomenon is referred to as "competition as collusive behavior" (Hirshman, 1970, pp. 26-29).

the nature of the production (resource flow) problem is affected by how the provision (resource stock) task is managed. The main task of providers is to create and maintain a reliable stock of the resource and therefore, CPR provision is typically a never-ending task. In CPR situations, users typically organize user groups or use local governments to perform the provision function.

Providers need to estimate the demand for the service, arrange for financing of the requisite facilities, and organize the monitoring of the production activities. Providers face a number of basic problems described below.

1. As it is difficult to legally exclude people from using electrical energy delivered over the same set of wires, there is a potential for free-riding which has to be overcome with careful monitoring and enforcement.
2. Multiple simultaneous users sharing the same set of infrastructure (wires) for subtractible goods and services implies that the users have to mutually agree to some form of monitoring and responsibilities despite the variability in the individual demand patterns.
3. Although monitoring of the energy consumed is possible, it is not easy to understand the preferences especially when faced with free-riding. As the preference structure is unknown, it is difficult to devise measures which reflect the benefits of the resource to the users.
4. Even if governmental agencies are involved in order to reduce free-riding, the system can suffer from rent seeking activities promoted by individuals and bureaucrats alike.

Providers typically manage the task by working on both the demand-side with the end users and the supply-side with the producers. On the supply-side, competitive wholesale markets will require that retail providers estimate and aggregate user demand and benefits accurately so as to make the best use of power marketers, generators, and all others who offer to sell wholesale energy based on market price mechanisms. Demand-side management (DSM) plans at the retail distribution level can indicate some of the problems related to provision. However, monopolistic utilities have opposed DSM planning to date and the customers did not have an exit (competition) mechanism to express their discontent. In fact, with competition (exit) per FERC Order 888, providers may continue to develop better DSM plans in order to better estimate demand patterns (Hadley & Hirst, 1995).

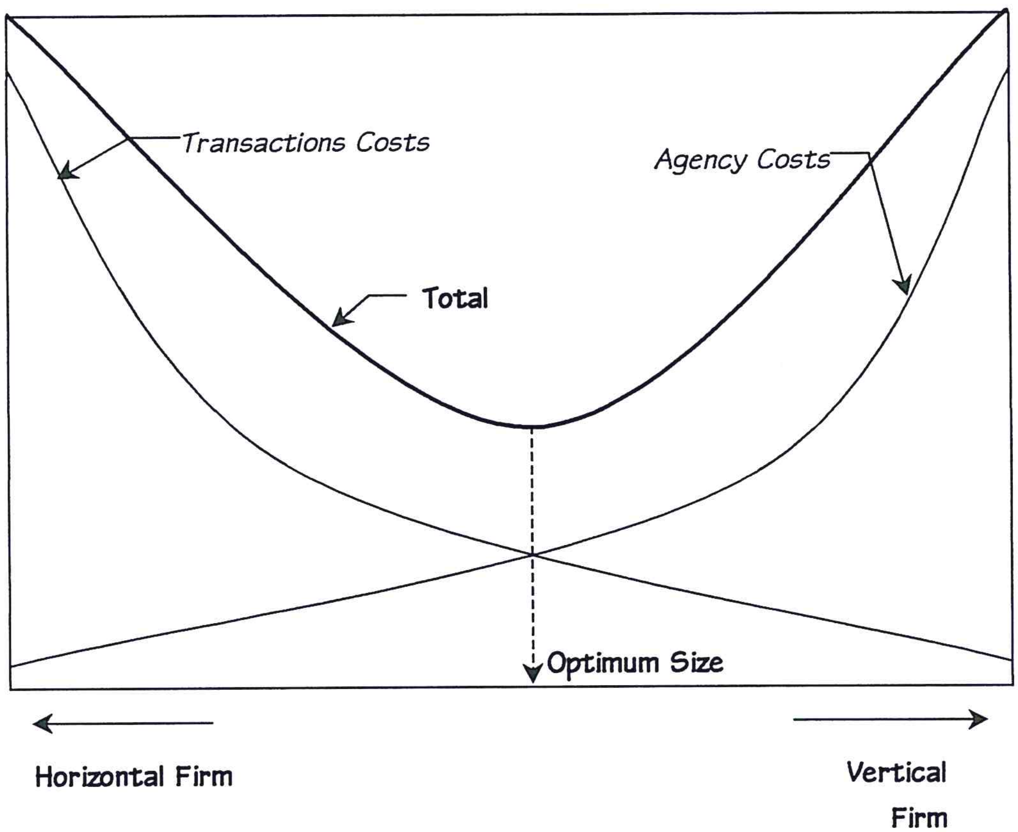
Therefore, the design problem is to find key features of CPR institutions at the retail-wholesale level, which affect their performance. On the supply-side, it appears that competition (exit) provides one effective mechanism which induces providers to meet the retail customers' needs. However, a formal complementary voice mechanism is needed on the demand side so that the retail customers' concerns are effectively incorporated.

Production

A producer in a CPR situation typically knows the production function, i.e., the relationship between the level of inputs and the resulting yield. The production itself can be carried out by participants of the CPR or outsourced. Typically, the producer sets the production level to its maximum microeconomic efficiency, i.e., where the marginal costs equal marginal returns. The producer also excludes potential beneficiaries through different monitoring and pricing methods. Finally, the producer manages the allocation of the CPR flow to the beneficiaries. With FERC's Order 888, the energy producer at the distribution level can either buy the power from the new wholesale market or produce energy locally using distributed generation and other alternatives. Therefore, an exit mechanism available at this retail-wholesale level for the function of production.

During production, different parts of the CPR at different times have different resource endowments and different levels of technology to extract it. The heterogeneity in the distribution of the resource and the availability of technology creates scenarios of uneven and potentially sub-optimal resource appropriation. The local producers can manage the production process and externalities by optimizing institutional structure in order to minimize the internal agency coordination costs (Jensen & Meckling, 1973) and external market transactions costs (Williamson, 1985). Figure 4 below shows a generic conceptual representation of the costs tradeoff as a function of the size of the distribution community (Gurbaxani & Whang, 1991). Many generalized mathematical and site specific models have been developed over the past three decades to assist in the production optimization process (http://eia.doe.gov/).

Figure 4 : Production Organization and Costs Tradeoff



Source: Adapted from (Gurbaxani & Whang, 1991)

Performance Metrics for CPR Institutions

Perhaps the most challenging part of managing the CPR is to identify and formalize metrics by which the performance of CPR institutions can be measured and evaluated. In production processes, the performance measurement task is concerned with how well the producers can allocate the yield based on a known production function in an equitable and efficient manner. Therefore, to judge institutional performance in production problems, it is important to define the meaning of efficiency and equity. On the other hand, in provision processes, performance measurement is concerned with how well providers can create and maintain the CPR.

Production actors include mainly generators of all types and public transmission and distribution systems; they assist communities manage the flow from the energy CPR. Typically, whereas the generators compete, the transmission and distribution system owners are regulated monopolies. Provision actors include mainly collectivities and their representatives; they assist communities manage the stock of the energy CPR by organizing the consumption, financing, monitoring the production of goods and services from the energy CPR. Providers are represented often by private ESCOs or by public power companies owned and operated by local governments.

In both cases, providers and producers select a method of demand estimation and of monitoring and verification based on the expected performance level. In fact, financing terms arranged by the providers are often tied to the performance guarantees required by the financial institutions. Demand estimation[35] and monitoring (IPMVP, 1997) are rapidly advancing sciences, intimately related to advances in metering techniques and telecommunications. Such rapid high impact changes in technology imply that the providers and producers both must be flexible to respond to changing needs and

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[35] Hourly demand estimation methods include: direct metering of each customer, upstream metering of customer groups, load research by direct metering of samples of customers, load profiling from historical data samples for various market segments, and regression modeling (Wright, 1997). Many private companies compete to provide demand estimation services (for example, see http://www.maisy.com).

capabilities. At the same time, they also must be able to rationalize and defend the consistency of their approach to their customers and financiers.

Performance in Provision

How well the producer can manage the CPR production and externalities is a local problem. On one hand, how different communities manage production is exemplified by performance based contracts negotiated with private ESCOs to increase energy efficiency (Hansen & Weisman, 1998). On the other hand, the large number of municipal and rural (public) power producers provide an example of how local governments have delivered electricity equitably (presumably) to their local citizens.

The institutional differences are because of the different methods of financing capital projects in the private and public sectors.

<u>Private Industry Performance in Provision</u>

One hallmark of the ESCO movement has been the involvement of the private sector in providing project finance. ESCOs essentially became participants in the projects that they implemented. To get financing from commercial and other lenders for community based energy projects, ESCOs use payment guarantees from their customer base and in return, provide the customer base a performance guarantee. By sharing project risk with the customers and lenders in many ways, ESCOs provide a model framework for the private sector to represent retail electricity customers.

Recently the states of Rhode Island and Massachusetts passed new legislation to establish standards for performance based rates for electricity at the distribution level (http://www.eua.com/pp4.html). Promoters of performance based regulation (PBR) have noted other experiments in the states of Maine, New York, and California as "attempts to align the incentives to shareholders with the interests of the customers, and to make them to some extent automatic" (Biewald et al., 1997). Most PBR related developments have been tailored to enable communities and ESCOs get to into a contracting arrangement with performance guarantees and to obtain good financing terms for various projects.

Starting from mostly DSM related improvements, the ESCO industry has developed capabilities in power purchasing (Cudahy & Dreessen, 1996). As energy prices and inflation have declined in the U.S. in the 1990s, the long lead times required for ESCOs have forced many companies and related capital financing institutions to countries abroad[36] where the ESCO returns are more attractive.

Several types of PBR contracts and measures are utilized in practice for verification of ESCO contracts [Hagler Bailly, 1996 #56] including guaranteed savings, PBR with shared savings or paid-from-savings, utility DSM, energy/output sales, and performance leases.

- Guaranteed savings contracts include an energy services agreement for the ESCO's technical services, and a financing agreement which covers the end-users' obligation to pay the project's initial costs.

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[36] In fact, the U.S. based ESCOs' mature expertise in formulating such contracts is being marketed actively by the U.S. government and financiers for project development abroad (Wolter, 1996).

- Utility DSM contracts are developed between the utility and an ESCO, who performs the work.
- PBR with shared savings requires periodic verification of savings and end-user payments. PBR with paid-from-savings requires the end users to directly pay the financing company from the savings realized.
- Energy/Output Sales Agreements require the ESCO to establish a distributed utility, i.e., to match the end users' load size and place generation equipment on site to minimize energy purchases and to sell excess power to a local utility.
- Performance leases are written to finance equipment purchase and maintenance by lease contracting by the ESCO with a guaranteed level of performance.

It is clear that most of the PBR measures are based on a goal to improve energy efficiency; contracts are not written to measure equity in the private ESCOs' allocation process. As the private ESCOs do not own distribution lines, the exit mechanism for the retail customer is clear; if the ESCO does not perform, replace it. With such competitive pressures, ESCOs have to perform

The second set of private companies who may play the role of providers are the regulated DISCOs. The potential for unbundling, PBR, and technological innovation make DISCOs strategic target opportunities for the private sector (Stone, 1996). Further, DISCOs are likely to change the nature of distribution networks by outsourcing activities[37] to numerous contractors.

There is no clear precedent yet on whether the DISCOs will be unbundled from other related provision activities. If the model separation imposed by FERC's Order 888 between regulated TRANSCOs and the Poolco functions at the wholesale level is any indication of the functional separation at the retail distribution level, many forms of local organizations could evolve to support communities with provision services. On the other hand, if the argument that vertically integrated, publicly owned distribution systems are efficient producers (Kwoka, 1996)[38] is used to allow the DISCOs to encompass provision activities, there will be regional monopolies like public power alternatives discussed in the section below.

Public Power[39] Performance in Provision

Like IOUs, most of the public power companies have been monopolistic during the decades of cost-of-service regulation (Kwoka, 1996). PBRs are not used for public power alternatives and like other monopolies, the exit mechanism option for retail

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[37] Outsourced activities may include line maintenance, supplies procurement, warehousing, streetlight installation and maintenance, substation construction and maintenance, customer information systems, metering, billing, and customer call centers.

[38] Small utilities and public power companies are noted exceptions (Kwoka, 1996).

[39] All local power companies, both large (http://www.lppc.org/), small (http://www.appanet.org/), and rural electric cooperatives (http://www.nreca.org/) will be addressed together as public power companies. However, very large multi-state power companies, Bonneville Power Administration and Tennessee Valley Authority, are not included in the present discussion of public power companies.

customers is weak. Financing of public power systems is accomplished with minimal performance based guarantees. Two weak forms of performance assessment of utilities has been tried in the past (Jaskow & Schmalensee, 1985) including franchise competition and benchmark (yardstick) competition.

- Franchise competition, where an auction is organized periodically to select one utility from a group of bidders to supply power to a specific service area.
- Benchmark or yardstick competition, where performance of the utility in question is compared against the performance of other utilities.

Other forms of performance assessment driven by "limited competition" have always been muted by the utility industry over a period of time. The muted methods of performance assessment included competition to capture valuable industrial customers, purchase of wholesale balancing power, and displacement (exit) by PURPA supported qualified facilities, cogenerators, and non-utility generators. Time and again, under the regulated vertically integrated structure, performance improvement and exit mechanisms were opposed and muted by the utility industry leading ultimately to wholesale competition forced by FERC's Order 888.

At the retail distribution level also, performance assessment of public power systems has been infrequent at best. As most public power systems also own monopoly over the distribution wires, the retail customer has no exit mechanism. In fact, public power systems oppose the enforcement of competition at the retail level and have been challenged in court for using their monopoly power to buy power at wholesale prices in the "municipalization" effort (Morgan, 1996). Further, public power has advocated the position that a regionally aggregated customer base should be represented by the local public power utility by default (Guinane, 1997).

Performance in Production

With FERC's Order 888, a new production related actor was brought upon the stage in the electric industry: the private power marketer. The main function of power marketers is to zealously pursue generation sources for the lowest cost electrical energy for various aggregations of consumers. The other retail producers will be the private ESCOs, and public power companies and regulated DISCOs.

The performance measures of each actor are substantially different. However, it is noteworthy here that improvement in the flow of energy is related to the capital intensive means of tapping various energy sources which, in turn, is primarily a function of the technology used to tap the energy CPR. It is also noteworthy that commercial success of the requisite technology innovations is a slow and long-term process in the energy industry (Rosenberg, 1994). The implication is that production is a long-term function requiring flexibility toward technologies to produce resource flows in the short-term at the best possible price (Rosenberg, 1994).

Private Industry Performance in Production

As an aggregator of customer demand first, the power marketer is expected to evolve into a fierce competitor, offering cut-throat pricing to the customer base and passing reductions in generation costs on to the retail customer. Although an unlikely long-term investor in technology, a truly independent power marketer can be an effective actor in pressurizing the generators find innovative technological solutions to cut costs.

On the other hand, ESCOs are typically participants in the financing of the retail power project. Therefore, ESCOs often share both short- and long-term goals of the community. Further, as private entities, ESCOs can tap several sources of finance, including commercial institutions, vendors, and special purpose funds [Hagler Bailly, 1996 #56] while maintaining a performance requirement and an exit mechanism for their retail customer base.

Public Power Performance in Production

A key technical difference between private ESCOs and the alternative municipal and rural power producers is that the public power producers typically also own and operate local distribution lines. In fact, the large utility industry has lodged several court cases against local public power utilities from "municipalization" based on an argument that their ownership of the local distribution systems was being used as a means of maintaining monopoly power over their consumers (Morgan, 1996).

Public power companies have tried to show their relative efficiency in comparison to IOUs by delivering electricity at a lower price (Anon, 1998b)[40]. Further, public power companies have made the argument that the reliability of publicly owned local distribution systems is higher than the distribution systems owned by the IOUs (RMI,

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[40] A claim contested by the IOUs who, in turn, claim that public power can price electricity cheaper because of various subsidies (http://www.senate.gov/comm/energy/general/competit2.html).

1996). Finally, public power companies show off their experience with distribution systems at local levels as an indicator of their production efficiency (Brown, 1997).

As such, public power companies often outsource their services to improve efficiency. In fact, they have contracted with ESCOs for implementation of DSM plans. However, proponents of public ownership also agree that significant scale economies make IOU based generation more efficient than publicly owned generation (Kwoka, 1996) but public ownership of distribution systems is shown to be more efficient than private ownership. However, the retail customer has very limited exit choices.

The regulated DISCOs also may be similar to public power companies in many ways, especially if they are allowed to bundle their services within their territories based on an argument of superior production efficiency (Kwoka, 1996). However, the role of DISCOs is still very much in the public debate arena. For example, although initial indications from California (http://www.energy.ca.gov/CADER/) are that state regulators might maintain a functional unbundling between private DISCOs and (local) distributed power generation and marketing.

Design Features of a CPR Institution

It is evident from the sections above that CPR institutions are diverse and yet there are some common features of all CPR institutions depicted in Table 3 above. The discussion also shows that both private and public organizations have attempted to measure and improve performance at the retail level. With this experience, it should be possible to design a general policy for retail-wholesale institutions. For example, Figure

5 below shows eight institutional design principles (Ostrom, 1992) derived from analogous CPR situations in irrigation network systems.

Figure 5 : CPR Design Principles

1. Boundaries of the service area and the customers with rights to use electrical power are clearly defined.
2. Allocation of CPR is proportionally equivalent to the local costs and benefits.
3. Most customers affected by operational rules for the CPR are included in a group that can modify the rules.
4. Monitors, who actively audit physical conditions and consumer behavior, are accountable to the customers and/or are the customers themselves.
5. Consumers who break operational rules receive graduated sanctions/charges from other consumers, from officials accountable to the consumers, or both.
6. Consumers and their officials have raid access to low-cost arenas to resolve conflicts between consumers and between consumers and officials.
7. The rights of consumers to devise their own institutions are not challenged by external governmental authorities.
8. Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises.

Source: (Ostrom, 1992, Ch. 4)

Such generic empirical design principles provide guidance on possible and desirable features of long-lasting CPR institutions at the retail-wholesale interface in electricity distribution systems. The specific rules governing a CPR in an aggregated community of consumers will vary and the design principles above present guidelines for the development of the operational rules. However, two inherent features of CPR institutions lead to significant challenges in their design: path-dependence and public participation.

Overcoming Path-dependence Through Flexibility

In a complex and dynamic environment, the design of institutions never ends and therefore, the rules have to be changed from time to time. In particular, such processes of institutional change are also driven by the type of "path-dependence" that characterizes technological change (Arthur, 1988).

Strong evidence of path-dependence in the energy industry (Rosenberg, 1994, Ch. 9) confirms that institutional rules have to be designed to be *flexible* to respond to such exogenous changes if the retail customer is to have access to an exit mechanism. Current evidence of exemplary exogenous changes projected to significantly impact the electricity industry over the next two decades are itemized below.

- Convergence of electricity generation with natural gas technologies (Wile, 1997).
- Distributed generation (Hamm et al., 1995)
- Convergence of electric utilities with telecommunications (Rivkin, 1996)

Flexibility typically implies that the responsibility to make decisions to suit local conditions is delegated to the local authorities. How responsibilities are delegated is the key design issue. For example, under the current regulatory regime, the state PUCs have been delegated substantial decision making power. As discussed earlier, most deregulation proposals prefer to delegate a substantial portion of the PUC's responsibilities to lower local levels, i.e., even to individual retail consumers themselves. Regulatory flexibility most likely will force (enable) local decision makers to manage the uncertainties in the path-dependent process and also provide an exit mechanism.

In such a dynamic and uncertain environment, incorporating *flexibility* into the provision function of the CPR institution becomes challenging. Further, given the capital intensive nature of energy equipment investment and the increasing scrutiny of retail consumers, decisions cannot be changed too fast either. In fact, "Because path dependence characterizes most processes of institutional evolution, all systems have limits to the degree and frequency of change that is feasible without destroying the advantages of predictable expectations created by a stable institutional process." (Ostrom, 1992, p. 62). Further, the inconvenience and transactions costs of switching strategies too often may not be justifiable.

In effect, there is a delicate balance between the changes that flexibility allows and the actual changes that the retail consumers consider justifiable. If providers of the retail-wholesale institutions were simply provided the carte blanche means to change decisions often, the customers will have access to the exit mechanism and lose voice. Therefore, it is important for the providers to be able to justify the inevitable changes in decisions. By making the providers of retail-wholesale responsible for justifying their decisions through periodic reviews, retail customers can maintain the mechanism of voice.

This research accepts the contention (Hirshman, 1970, Ch. 9) that there is no single, stable mix of exit and voice, and that "an awareness of the inborn tendencies toward instability of any optimal mix may be helpful in improving the design of institutions that need both exit and voice to be maintained in good health." (p. 126) Further, it appears that "By bringing out the hidden potential of whatever reaction mode is currently neglected, it could encourage resort to either exit or voice, as the case may be." (p. 126) In the electric industry, as a formal exit mechanism (competition) is introduced through the competitive restructuring process, it is important to also inject a formal voice mechanism at the retail level.

Justification: An Instrument for Public Participation

To maintain the delicate balance between flexibility (exit) and justification (voice) is difficult because the decision structure is not fully in place. In particular, as technology is adapted, the decision structure itself evolves and therefore, changes in the mix of exit and voice are inevitable[41]. In the open socio-political environment of the US, public participation provides a voice mechanism for retail customers. Public participation is often institutionalized through mechanisms of transparency and public comment in policy making. Public officials (and CPR providers) often cater to the concerns of the participating public by justifying changes in decisions by demonstrating that all decisions follow an open, *consistent and hence defensible* process.

The importance of consistency and defensibility in the decision making process was recognized and formally specified in the landmark Superfund legislation in 1986 to clean

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[41] (Hirshman, 1970) notes "*each recovery mechanism is itself subject to the forces of decay...*" (p. 124)

hazardous waste sites in the US. Policy makers of the US Environmental Protection Agency (EPA) legislated the requirement for consistency and defensibility in the process of selecting the method of remediation of Superfund sites. Although EPA's Remedial Project Managers were tasked to pick a method in a consistent and defensible manner, there was little guidance on what was meant by consistency and defensibility and on how to achieve it. Subsequent debates on the consistency and defensibility of the decision making process were not only academic but led to a so many lawsuits that the Superfund program has been crippled in the courts ever since. The valuable lesson learned from the Superfund experience is that policy makers must provide specific guidance (a model) on what is meant by consistency and defensibility in the decision making process and the tools to implement it.

The task of developing a consistent and defensible process and the tools to implement the process is particularly difficult because of inter-related changes caused in the system by small, incremental decisions. The task is even more challenging because of systemic uncertainties which force decision makers to revise (even retract) plans when unexpected situations arise. For example, when technologies and people perform differently from what was expected, plans have to be revised in a consistent and defensible manner.

The inability to manage and justify (explain) the complex path-dependent process to the satisfaction of the retail customers is a subtle, critical bottleneck in policy design.

Often, the inability makes public participation an adversarial and difficult process[42] and, in turn, makes the voice mechanism ineffective. Conversely, to design an effective voice mechanism to complement competition (exit), a formal methodology is needed to manage and justify the providers' complex, path-dependent decisions to their retail customers.

Summary and Research Issues

The existing variety of institutional forms described in the section above appear to confirm the micro-economic observation that "the industry supports a diversity of forms, each more or less in place where it has a comparative advantage and best contributes to the common performance objectives" (Kwoka, 1996). Although this statistical observation presents the *ipso facto* status of the industry, it is not surprising to find the diversity of organizational forms in most CPR situations (Ostrom et al., 1994).

The design of a generalized policy for the diverse set of retail-wholesale institutions is challenging because of the phenomenon of path-dependence. With technological and

[42] Further, classic case studies (Barrett & Sahlman, 1976; Virgil, Nord, & Sterling, 1973) show that in decentralized organizations, managers do not always reveal full and accurate information to others in order to maximize self interest. Such gaming is often discouraged by management control systems, which are designed to formally or informally investigate claims of inaccurate and incomplete reporting.

other uncertainties, path-dependence affects the ability of retail-wholesale providers in justifying their decisions to the CPR participants and stakeholders. A methodology for overcoming path-dependence could assist the retail-wholesale providers in justifying their decisions and, in turn, make the voice mechanism more effective.

CHAPTER 5

THEORY: MODELING RETAIL ENERGY INSTITUTIONS

As described in Chapter 2, the intent of EPAct is to provide an exit mechanism for the consumer and, in turn increase customer choice, from the potentially "lazy" monopolies set up by vertically integrated electric utilities. Therefore, in this research the benefit is defined to be the increase in customer choice, i.e., by allowing retail customers to use an exit to switch providers without sacrificing their complementary mechanism for voice (Hirshman, 1970). Therefore, an institutional form that maximizes retail customer choice is the optimal design, with the precaution that the customers do not lose the mechanism of voice in the process. Chapter 3 showed that the existing policy framework of decentralization is not by itself adequate for prescriptive policy design for retail-wholesale institutions.

Chapter 4 confirmed that the organizational forms at the retail-wholesale interface of the electric industry are diverse (Kwoka, 1996) and that they can be characterized as varieties of CPR institutions. To design a generalized policy framework, the key feature is path-dependence, which makes voice ineffective in provision functions. Therefore, the analytical task is to develop methods, which can assist retail-wholesale institutions in improving their performance by managing path-dependence.

The sections below first describe several potential analytical approaches. Upon evaluation, an artificial intelligence (AI) based modeling method is proposed.

CPR Institution Modeling Methods

The previous section showed that to manage path dependencies effectively, the key features of the CPR institution are *flexibility and justification*. Flexibility (exit) is provided through customer choice - the policy aim of current restructuring efforts. However, justification (voice) needs to be provided at the retail level by implementing consistent and defensible processes. The design problem then is to make a model of a CPR institution at the retail-wholesale interface, which has the desired features of flexibility and justification.

The previous sections also showed that three types of challenges make it difficult to design CPR situations with the features of flexibility (exit) and justification (voice). First, our knowledge about CPR situations is often incomplete, especially in dynamic situations. Second, flexibility is required to manage uncertainty because it enables decision makers to retract and revise previously made assumptions and decisions to accommodate new information. Third, the requirement of consistency and defensibility implies that decision makers must first be able to explain the rationale leading to their sequence of decisions. The three inherent challenges arise often in CPR management as discussed below and therefore, institutions have to be designed to manage them.

In essence, by definition[43], the management of CPR goods requires more active and routine participation as exemplified by classic examples in infrastructure management (Ostrom et al., 1993). The burdensome management needs of CPR situations also demand frequent changes in the rules-of-thumb (heuristics) used by participants (Ostrom et al., 1994, Ch. 15) to manage the complex systems. Frequent changes in the heuristics used to manage CPR situations are characterized by path dependencies (North, 1990).

In this section, we see that to create a model of a CPR institution, it is useful to embed these features in the representation[44] itself; a rich representation makes it possible to apply powerful inference mechanisms, such as behavioral rules, to operate on them. Representations are linguistic formalisms; they allow us to express facts so that we can reason with them and develop models.

In the simplest form, representations are glossaries and terminologies, which allow us to agree on a set of symbols that share common meanings. At a complex level, representations are languages, which allow us to express specific thought patterns in different ways and in turn, enable greater reasoning.

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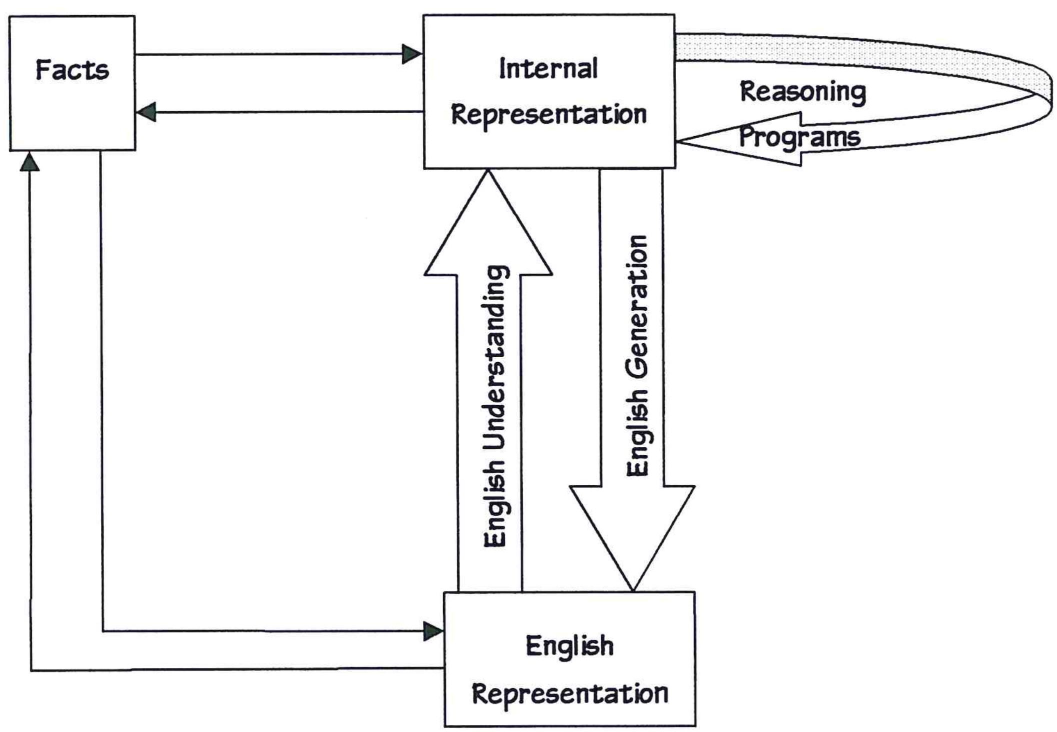
[43] The three challenges are particularly important in CPR situations as compared to other types of goods (Table 3) - public, private, or toll. In particular, although it is difficult to exclude non-payers in both CPR goods (like groundwater) and public goods (like air), the CPR goods are typically finite in supply and do not allow rival consumption. Therefore, to avoid the risk of stock depletion, participants have to be involved much more actively in the management and replenishment of CPR stocks (Hardin, 1994) than in public goods. On the other hand, although private goods require as much management of stocks as CPR goods, the difficulty of excluding non-payers puts an additional enforcement and management burden on CPR managers.

[44] That is, the expression or designation by some term, character, symbol, or the like. (Webster, 1995)

For example in Figure 6, facts represented in English may be stated as "The average electrical consumption is U.S. households is 80,000 British Thermal Units per day (BTU/day)." If the internal representation of electric power can be in units of BTU or kiloWatt-hours (kWhr), a simple reasoning program could deduce that at a conversion rate of 3,413 BTU per kWhr, the power consumption per household is approximately 1 kW. The representation is even more useful if it can represent electric power in units of work, such as horsepower, i.e., a more powerful representation allows more reasoning.

Figure 6 : Importance of Representation in Modeling



Source: (Rich, 1983, p. 136)

Representations are weak or strong; they can also be formal or informal. For example, the English language is a set of formal rules, but English expressions can be ambiguous and weak. In contrast, the Sanskrit language is more formal and less ambiguous and yet, it is perhaps too rigorous to express routine (informal) expressions. The language of mathematics and logic is formal and strong; an inherently useful formalism for technical reasoning. On the other hand, mathematics provides an incomplete set of symbols for expressing knowledge in the arts and social sciences. Music, art, economics and other fields have in fact become disciplines by developing a representation language of their own to server their specific purpose[45]. Often, concepts from more than one scheme or representation are useful, i.e., representations are not always mutually exclusive.

Until recently, the term "institution" was used to represent many types of organizations in different ways. A generic grammar of institutions is a recent development (Crawford & Ostrom, 1994) in the field of political science. A formal generic grammar enables researchers in describing and modeling institutions using a standard terminology. It is the first step toward describing a stylized version of the organization – or in other words, it is the first building block of a representation. In this research, the representation initiated in the grammar of institutions is expanded to incorporate the following capabilities.

1. Flexibility in decision making, i.e., the ability to make decisions based on assumptions and then change them.

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[45] In computer science, establishing new languages to control complexity is referred to as metalinguistic abstraction (Abelson & Sussman, 1996). In this context, it is not surprising that people find it difficult to understand others from different disciplines using different languages.

2. Consistency and defensibility of the decisions made in dynamic CPR situations, i.e., the ability to explain the rationale behind the decisions in a consistent manner even when previous assumptions have to be retracted.

Consequently, conventional representation techniques face several limitations as described in the sections below.

Conventional Monotonic Representations

Three types of conventional representations and their relevant features are described in the sections below. They are calculus-based representation, enumerated game theoretic representations, and agent-based simulation representation. All the three representations are monotonic in nature. Monotonicity is a property defined as follows. If a formula **p** is derivable from a set of premises **Q**, then **p** is also derivable from a superset of **Q**. For example, if an ESCO chooses a generation technology (**p**) based on certain set of data about the known performance characteristics (**Q**); a monotonic decision (**p**) will also be derived when additional information about the technology (superset of **Q**) is obtained.

In cases where there is path-dependency, the conclusions derived at every stage of the decision process is dependent on the decisions taken and information obtained in the past. In practice, such decisions often require decision makers to address conflicts in data and sometimes even force them to retract previously made decisions to accommodate new information. The following sections show that as such, monotonic representations are not able to model such path-dependencies.

Calculus Based Representation

The advantage of calculus based representation methods is the elegance of operations that can be applied to them. For example, if it is known that the consumers' benefit function can be represented as a continuous curve, calculus provides definitive methods of maximization of the benefit. However, such representation is not easy to model CPR institutions for several reasons.

First, a complete mathematical calculus based representation of CPR institutions (Clark, 1990) requires knowledge and data that are simply not available to actors with bounded rationality (Simon, 1994). Further, experience in energy modeling (Odum, 1983), water resource networks (Rogers & Fiering, 1986), and commodity system dynamics (Forrester, 1968) shows that many decision variables are often discontinuous[46]. Discontinuities lead to many local optima in practice and an inverse function is not easily defined. Therefore, operations research (OR) techniques (Eppen, Gould, & Schmidt, 1988) are difficult to use on a calculus based representation. Finally, the simplex algorithm, which forms the basis of OR techniques, is a monotonic constraint satisfaction algorithm with a unique solution strategy for a completely specified problem. In situations where knowledge of the domain is incomplete and where conflicting conditional constraints have to be resolved, OR techniques may not provide the diversity in methods needed for problem solving (Polya, 1957).

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[46] Specific electricity related examples of discontinuities in technical variables include transmission and distribution line capacities, boiler pressures and capacities, gas line pressures and temperatures, etc. Other discontinuous decision variables include must run units for merit order dispatch, fuel type preferences, etc.

In addition to the representation and data related problems noted above, it is important to consider three other aspects of the process of artifact design (Simon, 1994).

- First, the nature of retail electric customers is different than policy planners for whom calculus-based representations have been used extensively. Being decision makers with bounded rationality, retail customers look for "good" solutions and not necessarily the most optimal ones. The only calculus-based technique, which incorporates the explicit concept of a "good" solution, is goal programming. However, goal programming relies on a pre-defined "pre-emptive priorities" (sequence) of application of constraints (Eppen et al., 1988), which monotonically lead to a solution. While it is recognized that changes in the sequence can lead to different answers, there is no formal mechanism to manage conflicting constraints.
- Second, retail customers typically have many other concerns and therefore, as in the case of home mortgages, prefer long-term contracts with some flexibility for change. Typically, the precision of calculus based techniques cannot be supported easily because of our inability to predict long-term behaviors. Expert judgement is often required to interpret results from calculus based models as the real conditions change from the assumed rationalizations.
- Finally, not being experts in energy engineering, retail customers cannot be expected to specify a firm objective function - a rigid requirement of calculus based representations. As objectives change, previously made assumptions may have to be retracted, leading again to non-monotonic conditions.

Enumerated Game Theoretic Representation

The application of game theoretic simulation is demonstrated in the classic "tragedy of the commons" (Hardin, 1968)[47]. In the many versions of the tragedy game (Kreps, 1990) under varying conditions of behavior, uncertainty, communication, decisions sequence, repetition, credibility, threat, and cooperation, modelers have simulated various CPR conditions and performance. CPR modelers typically simplify the game problem so that more manageable simulation techniques similar to dynamic programming[48] could be applied (Ostrom et al., 1994). Recently, game theory was applied for evaluating complex electric transmission access and pricing policies (Kelly, Hobbs, & Eifert, 1990).

The advantage of game theory is that for simple problems involving a few players, it provides an explicit and elegant rationale for decision making based on the specified behavior of rational and knowledgeable actors. Many fully specified games also can be converted into a matrix of simultaneous equations and solved thereafter using OR techniques (Goodman & Ratti, 1975). However, the use of game theory has been constrained in practice because of well-known limitations (Raiffa, 1982).

1. Game theory requires the ability to compute (enumerate) payoffs from a game to its participants in all possible situations, i.e., it assumes complete knowledge of the CPR situation. It is not possible to draw inferences from incomplete information.

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[47] In a later note (Hardin, 1994), a clarification was provided that the tragedy referred to an unmanaged commons and that potential management solutions do exist to avoid the tragedy.

[48] Dynamic programming is applied in effect as a partially enumerated backward induction technique to achieve subgame perfection for each round of the CPR situation represented as a game.

2. In game theoretic representation, participants are assumed to be fully rational although the assumption has been modified in recent CPR modeling efforts to incorporate individuals displaying bounded rationality (Ostrom et al., 1994). Heuristics used by individuals with bounded rationality to solve complex and uncertain problems are represented in the rules of the game. However, there is no mechanism to make rule changes or to explain which rule led to a particular result.
3. Analysts often have resorted to the related rigorous probabilistic decision theoretic methods to overcome situations where games are played in uncertain situations. Use of probabilistic methods requires a careful analysis of independence of variables and an estimation of prior and conditional probabilities (Benjamin & Cornell, 1970). Individuals with bounded (Simon, 1994) and quasi-rational (Thaler, 1992) behavior do not display the rigor required in such highly rational analysis in normal CPR situations.
4. As in calculus based representations, our inability to forecast accurately in the long-term limits the rational game theoretic methods to a short-term time horizon. Retail electric clients who hope to obtain long-term contracts cannot hope to model their forecasts on game theoretic models alone.
5. To model strategies used by CPR participants with game theoretic models, it is necessary to understand the social psychology of groups of individuals in a CPR situation. Significant research needs to be done in this field (Ostrom et al., 1994) and therefore, it is not easy for retail customers to specify an objective function for a game theoretic model a-priori.

Distributed Agent Simulation

Agent based representation has its roots in the observation that microscopic actions of a collection of actors may lead to the emergence of unexpected macroscopic behavior (Schelling, 1978)[49]. It is not the object of this research to discuss the observation or to resolve very fundamental issues about the causes of emergent phenomena, such as nonlinear behavior, simultaneous interactions, the law of large numbers, or feedback in complex systems. However, it is important to keep the issues at hand to understand the pros and cons of agent[50] based representation techniques for CPR situations.

The observation that simultaneous interactions between actors lead to different outcomes than serial interactions is studied extensively in computer science research leading to the development of massively parallel computer architectures (Hillis, 1985). Recent attempts to develop models of social interaction have confirmed that much more basic research is needed to understand the "decentralized mindset" which appears to be at work in massively parallel environments (Resnick, 1997). A study of a decentralized mindset in CPR situations will require a significant amount of field information, which is not readily available and it is not the thrust of this research effort.

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[49] In the debate between the utility of studying the microbehavior of agents versus the macrobehavior of systems, it is tempting to draw parallels with the duality in physics that *"matter behaves in some circumstances like a particle and in others like a wave"* (Halliday & Resnick, 1990, p. 1203).

[50] The exact meaning of an agent is unclear. While proponents emphasize their (aggregation) role in bottom-up modeling, proponents of top-down methods (Simon, 1994) claim that it is simply a matter of disaggregating systems into nearly decomposable parts so as to simulate interesting system characteristics.

Another area in computer science leading to research in agent based modeling is distributed computing which was originally concerned with the development of tools and techniques for coordinating distributed software processes (Filman & Friedman, 1984)[51]. For the past decade, research has shifted to the use of emergent properties of distributed systems (Huberman & Hogg, 1988) and decentralized coordination of computer system resources with auction mechanisms (Bogan, 1994). However, the research generally assumes the use of a Walrasian market (Wellman, 1993) or auction (Domowitz, 1991 June) algorithms as preferred methods of "decentralized control." These methods represent mathematically complete systems and therefore do not provide a basis for representing incomplete CPR situations. Examples of recent application of agents also are based on interactions through auction (Ygge, Akkermans, & Andersson, 1998) and market based barter (Ruusunen, 1992) for electric utility applications.

Recent simulations of social phenomena in the laboratory (Epstein & Axtell, 1996) and in the field (Gilbert & Doran, 1994) based on serialized interactions between many agents with simple localized rules of behavior also have shown the emergence of a global macro-behavior. Agent based modeling also has been used (Axelrod, 1997) as a method to study (and not represent accurately) the emergence of fundamental social processes of competition and cooperation between adaptive actors. The explanatory nature of the agent based simulation technique provides little for this research, which aims to develop a representation for prescriptive modeling of a CPR situation.

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[51] There are many conceptual similarities with concurrency issues addressed in network operating systems and distributed databases., e.g., designing to avoid deadlocks (Abelson & Sussman, 1996).

Artificial Intelligence

Tools and techniques developed in research in artificial intelligence (AI) provide useful formalisms for several of the representation related issues discussed earlier (Rich, 1983). In particular, AI methods offer a mechanism to represent incomplete knowledge about a situation by emulating the representations used by human experts. By emulating human experts, who represent incomplete situations routinely, it is hoped that the resulting system will produce results that are as good as the expert's results. In fact, unlike the conventional calculus and game theoretic representations of complete systems described above, AI methods do not guarantee optimal solutions. AI researchers only promise "good" solutions to incomplete problems, just like the experts that they try to emulate[52].

Institutions as Rule Based Systems

In the development of a grammar of institutions (Crawford & Ostrom, 1994), a common representation for institutional statements[53] is developed to describe institutions

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[52] A comparison between AI and OR techniques is warranted here. In incompletely defined situations where the expert uses a simplex algorithm to find optimal solutions by "satisficing" heuristic constraints, a goal programming (GP) formulation may emulate the expert. In such incomplete situations, AI based search techniques and GP methods may be combined to manage the influence of pre-emptive priorities placed on the sequence of applications of achievement functions (Bodington & Elleby, 1988).

[53] An "institutional statement" is defined (Crawford & Ostrom, 1994) to "encompass a broad set of shared lingustic constraints and opportunities that prescribe, permit, or advise actions or outcomes for actors." It reflects the notion that "All three approaches (institutions as shared equilibrium strategies, norms, and rules) offer institutional explanations for observed regularities in the patterns of human behavior. The differences relate primarily to the grounds on which the explanation for the observed regularities rests."

as shared equilibrium strategies (von Hayek, 1945), norms (Ullmann-Margalit, 1977), or rules (Commons, 1968). The description below shows how AI methods can provide a natural mechanism to express institutional statements as "rules of thumb" or heuristics in a rule based (expert) system.

The institutional grammar consists of five components and institutional statements use a combination of components to describe the institution. The five components of the grammar are ATTRIBUTES, DEONTIC, AIM, CONDITIONS, and OR ELSE (ADICO).

- ATTRIBUTES specify the scope, i.e., "who" the statement applies to.
- DEONTIC consists of three modal verbs, may (permitted), must (obliged) and must not (forbidden).
- AIM describes the actions to which the DEONTIC is applied.
- CONDITIONS describe when, where, how, and to what extent the actions (in AIM) are permitted, obligatory, or forbidden (in DEONTIC).
- OR ELSE notes the sanctions imposed if the institutional statement is not followed.

ADICO components are combined in different ways to formulate different institutional statements and, in turn, describe different institutions as shown in Table 4 below. The ADICO grammar provides the first step toward a representation of CPRs situations. The grammar serves the same purpose as functional descriptions of computer programs presented in a Backus-Naur form. However, the ADICO representation does not capture knowledge about how the rules are used by CPR participants in problem solving.

Table 4 : Institutional Statement Components

ADICO Component	Shared Equilibrium Strategy	Norms of Proper & Improper Behavior	Rules of Behavior to Follow
ATTRIBUTES	✓	✓	✓
DEONTIC		✓	✓
AIM	✓	✓	✓
CONDITIONS	✓	✓	✓
OR ELSE			✓

Examples of ADICO institutional rules for retail electric institutions are as follows.

- Shared equilibrium strategy:

  <A: UTILITY> <I: LOW PRICE OF SERVICE> <C: GENERATION PLANTS ARE FOSSIL FUEL BASED>

- Norm:

  <A: UTILITY> <D: MUST> <I: PAY CARBON TAX> <C: GENERATION PLANTS ARE FOSSIL FUEL BASED>

- Rule:

  <A: UTILITY> <D: MUST> <I: PAY AVOIDED COST> <C: QF DISPATCHES POWER> <O: PENALTY FOR NON-COMPLIANCE WITH PURPA>

Once institutional statements are formulated, the ADICO grammar of institutions enables the analysis of any institutional game within game theoretic constructs (Crawford & Ostrom, 1994) as long as all the payoffs for the complete game, i.e., AIM values, can be computed. If all the payoffs cannot be enumerated, deductive principles of game theory may not provide additional value.

Using AI methods, *rules are represented as heuristics* in an {IF <Antecedent> THEN <Consequent> ELSE <OR ELSE Consequent>} form in the knowledge base. The institutional statements above can then be encoded as follows.

- Shared Strategies: IF <CONDITION> THEN <ATTRIBUTES, AIM>

  IF <Generation Plants are Fossil Fuel Based >

  THEN <Utility > <Low Price of Service>

- Norm: IF <CONDITION> THEN <<ATTRIBUTES, DEONTIC, AIM>

  IF <Generation Plants are Fossil Fuel Based >

  THEN <Utility > <Must> <Pay Carbon Tax>

- Rule: IF <CONDITION> THEN <ATTRIBUTES, DEONTIC, AIM> ELSE <OR ELSE>

  IF <QF Dispatches Power> THEN <Utility> <Must > <Pay Avoided Cost >

  ELSE <Penalty for Non-compliance with PURPA>

Once encoded, AI methods allow the application of any *inference mechanism*. For example, an inference mechanism to apply deductive game theoretic principles can also be applied if payoffs can be enumerated completely. On the other hand, other inference mechanisms may also be applied; their advantages are described in Appendix A.

<u>Institutions as Contexts</u>

The previous section showed that rule based AI systems may be able to provide a powerful scheme for representing CPR institutions. Further, the section showed that the rule bases could reason with a frame-based representation of hierarchies of institutions.

However, representation schemes provided by the rule and frame based AI systems are limited to more or less a static description of the institution.

The issue of representing dynamic behavior of institutions is particularly important in order to embed the features of *flexibility, consistency, and defensibility* as described earlier. Flexibility in decision making is needed for the institution providers to respond to exogenous changes, e.g., technology change. Flexibility is also needed so that decisions made in an uncertain environment can be retracted after new facts are discovered. However, to ensure that the flexibility is used in a justifiable and reasonable manner, it is important for the providers to keep the process of decision making consistent and defensible. Flexibility provides the exit, but consistency and defensibility provides the voice; and both are needed for maximizing customer choice.

Flexibility can be embedded into the representation by adding a time tag to each instance and searching the state space for solutions. However, representing facts that do change and the facts that do not change is not a trivial issue in an interdependent sequence of states. The most challenging problem in representing a sequence of states is called the *frame problem* (McCarthy & Hayes, 1969); it describes the difficulties involved in retracting facts asserted into the knowledge base and all decisions that are a consequence of those facts.

For CPR providers, the frame problem makes it difficult to maintain *consistency and defensibility* because most CPR situations are non-monotonic[54] - where reasoning requires adoption of (best available) assumptions that may have to be retracted later in light of new information. AI methods suggest that to reason in a non-monotonic CPR situation, the providers should make the "closed world assumption," that all qualifications to the problem are stated explicitly (reasoning by circumscription) and that the relationships not explicitly stated do not hold (reasoning with defaults).

Given the closed world assumption, AI methods offer a suite of techniques, which can be used by providers to follow a consistent and defensible process of decision making, with the following excerpt (Rich, 1983) describing the challenges to be faced.

> Nonmonotonic systems are harder to deal with than monotonic ones because it is often necessary, when one statement is deleted from the knowledge base, to go back over other statements whose proofs depend on the deleted statement and either eliminate them or find new proofs that are valid with respect to the current knowledge base. Deleting a single statement may have a significant effect on an entire knowledge base, since all proofs that depend on the statements whose proofs have just been discarded (and for which no other proof can be found) must be thrown away, and so forth. In designing nonmonotonic systems, it is

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[54] In logical terms, monotonic situations are such that the addition of new axioms to an existing set of axioms never reduces the number of theorems. In contrasting non-monotonic situations, the addition of new axioms may reduce the number of theorems.

> important to try to ensure that the system does not spend all its time propagating changes around.
>
> In order to propagate changes in the database and to check proofs for current validity, it is important to store, along with each theorem, its proof, or at least a list of other statements on which the proof depends. This is not necessary in monotonic systems since, once a proof is found, it need never be re-examined. Thus nonmonotonic systems may require more storage space, as well as more processing time, than monotonic ones. (p. 180)

The truth maintenance system (TMS) concept was developed (Doyle, 1979) to support non-monotonic reasoning. As such, the TMS simply maintained consistency among the statements generated by another program. On detecting an inconsistency, the TMS used a dependency directed backtracking (DDB) mechanism (Abelson & Sussman, 1996) to resolve the situation by modifying a minimal number of past beliefs. Significant improvements in performance and capability led to the development of a family of TMSs (Forbus & de Kleer, 1993) and in particular, to the assumption based truth maintenance system (ATMS) (de Kleer, 1986).

There are only three commercial implementations of the ATMS (Forbus & de Kleer, 1993)[55]. The KEE™ system selected for an exemplary prototype (Chapter 6) is briefly described in Appendix C. The next chapter shows how the ATMS can be used to provide

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[55] The Knowledge Engineering Environment (KEE™) by Intellicorp, Mountain View, CA, USA, the Automated Reasoning Toolkit (ART™) by Inference Corporation, Los Angeles, CA, USA, and Joshua by Symbolics, Inc., Bedford, MA, USA.

a representation for a CPR situation based on rule and frame based AI systems and also to incorporate flexibility, consistency, and defensibility.

Summary and Research Issues

A convenient way of summarizing the pros and cons of the techniques presented above is by evaluating how they fare vis-à-vis criteria for the design process (Simon, 1994).

Table 5 : Comparison of CPR Modeling Techniques

	Calculus	Enumerated Game Theory	Distributed Agents	Artificial Intelligence	Why AI?
Key Feature of Representation	Continuous Functions	Payoff Matrices	Massive Parallelism, feedback	Non-monotonicy, qualitative	Only AI qualifies
Data Requirement	Large, numerical, predictive	Small, numerical, explanatory	Large, qualitative, explanatory	Small, qualitative, prescriptive	Symbolic, qualitative, prescriptive
Nature of Customers	Policy planners	Management strategists	Social theorists	Community leaders	Bounded rationality
Time Requirement for Design	Short-term rationality	Short-term rationality	Long-term evolution	Long-term in short increments	Incremental satisficing with AI
Design Process Without Goals	Need Objective Function	Need Payoff Matrix and Objective Function	Specify emergence by chance mechanism	Incremental construction of model by search	Non-monotonic changes in goals

CHAPTER 6

IMPLEMENTING CONSISTENT AND DEFENSIBLE PROCESSES

There are several examples of potential applications of non-monotonic representations to model consistent and defensible processes in the evolving electric industry. To clearly distinguish the AI-based representation applications from conventional ones, a carefully selected example has been implemented in this research. First, a few potential examples of decision-making processes, where consistency and defensibility are important, are discussed to contrast AI-based and conventional representations. Second, the selected example of decision making by an ESCO manager is presented in detail. Finally, the AI-based implementation of the decision making process is described.

Exemplary Decision-Making Processes

The examples of decision-making processes presented below are progressively more suitable for AI-based representation. The first example presents the case of proposed coordinated multilateral trading, where the implementation of an attractive policy proposal may be otherwise hampered by the complexity of its implementation. The second example describes the potential application of AI-based representation in the increasingly important capability of customers to use dynamic scheduling to dispatch alternative suppliers of power in real-time.

Coordinated Multilateral Trades

Most proposed market exchange (auction) mechanisms are variations of three implemented highly ISO dependent centralized systems itemized below (http://www.energy-exchange.com/).

- Bid-based economic dispatch: Used in the United Kingdom to mimic centralized economic dispatch by requiring start-up, no-load, and running cost bids by the generators.
- Supply and demand curve bidding - Used in Norway, Australia, Alberta (Canada), and California (US); requires bidders to provide supply and demand curves which are used to solve for price and scheduled quantity in a transmission constrained centralized process.
- Centralized bid-based nodal pricing: Being implemented in the New York and PJM pool in the US; similar to the UK's bid based economic dispatch except that the algorithms use nodal energy prices and transmission congestion prices to solve the centralized optimization problem.

Alternatives to the centralized systems are simple decentralized algorithms, which enable power schedulers to act as brokers for consumers and producers. Such algorithms may appear attractive on paper[56] for implementing retail customer choice, but cannot guarantee both the economics and the security (reliability) of the electric power network. Therefore, using multilateral trading, an approach to balance the decentralized and centralized systems was developed[57] (Wu & Varaiya, 1995) so that the role of the ISO was reduced to guaranteeing security of the system without either compromising economic efficiency or impeding market exchange between actors (Varaiya & Wu, 1997). Simulation using field data and optimal power flow (OPF) algorithms have shown the multilateral trading concept to be promising (Overbye, Sauer, Gross, Laufenberg, & Weber, 1997). Because the multilateral trading approach makes only demands on the capabilities and moderate demand for additional information resources, it appears to be extendable to retail markets.

The elegance of the MinISO approach is not easy to translate into a system that can be used by laypersons and retail consumers. For example, one of the major debates that led to the development of the underlying multilateral trading model surrounds complex issues in the use of Folk theorems to analyze transmission access (Oren et al., 1994). The difficulty of understanding the implications of Folk theorems by CPR participants has been well recognized (Ostrom et al., 1994, p. 18). In electrical systems, the critical difficulty for the consumer is to take the inputs provided by the MinISO, such as OPF solutions consisting of loss vectors and congestion constrained Jacobian matrices, and arrange local multilateral trades. Further, the retail consumer needs to adjust multilateral trades based on changes in the OPF solutions upon notification by the MinISO.

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[56] See for example theoretical descriptions of emergence (Baas & Emmeche, 1997), coalition formation models (Sandholm & Lesser, 1995), and simulation of decentralized exchanges (Albin & Foley, 1992).

[57] Originally by the University of California Energy Institute, Berkeley, California and now researched by the Power Systems Energy Research Consortium (PSERC), Cornell University, Ithaca, New York.

Retail consumers have two choices in resolving the complexity of the problem offered by the MinISO approach. First, each retail consumer may develop an OR based algorithm to define and optimize their multilateral trades every time the MinISO provides a notification of a new OPF solution. On the other hand, the retail consumer may accept "good" solution through the satisficing method presented by an AI-based approach (Ignizio, 1997).

In an AI-based approach, the OPF solution notification forms a part of the retail customer's context. When new OPF solutions are provided over time by the MinISO, the retail customer has to renegotiate the multilateral trades. Expert retail customers would distinguish themselves by having the knowledge to make and update their multilateral trades. The process is non-monotonic. In the AI-based representation, the knowledge could be represented as heuristics and as bidders change their prices and quantities, the system could provide a "good" solution - like the expert. Also like the expert retail consumer, the non-monotonic system will be able to provide a justification for each change in multilateral trade based on the sequence of applications of heuristics in the different contexts.

On the other hand, in this example, an OR method, such as goal programming, also may be used to optimize the selection of multilateral trades every time. The OR method may not be easy for the layperson or retail consumer to comprehend, but the "black box" approach may be provided with the justification that the formulation automatically leads to an optimal solution. Both AI and OR approaches may be suitable in different situations for different retail consumers.

Dynamic Scheduling and Dispatch

One of the principles enshrined in the US legislation of the electric industry is the "obligation to serve" which binds suppliers and the electric network to always produce power in anticipation of user demand so that it is always available. The obligation is challenged to some degree when market forces are allowed to let suppliers provide power to only those who can pay. Nevertheless, the inability to exclude non-payers easily from the electrical field makes it imperative that user demand be forecast and scheduled as closely as possible. Further, the inevitable mismatch between forecast demand and actual demand requires some coordination of the dispatch of power in real time from generators to customers via the grid infrastructure. So delicate is the power balance issue that proponents of centralization argue about the natural need for the scheduling and dispatch functions to be the responsibility of the PX and the ISO.

The services required to maintain the delicate balance are called ancillary services. The suite of ancillary services are "those functions performed by equipment and people that generate, control, transmit, and distribute electricity to support the basic services of generating capacity, energy supply, and power delivery" (Hirst & Kirby, 1996). The FERC's Order No. 888 includes *pro forma* tariffs for six types of ancillary services based on traditional cost-of-service estimates. There are several definitions of ancillary services in industry costing the consumers approximately $12 billion per year and there has been research conducted about the potential for creating competitive markets for an unbundled set of ancillary services (Hirst & Kirby, 1997b). The following paragraphs discuss the rationale for alternative representations for some ancillary services, such as dynamic scheduling and dispatch.

The dispatch function is closely related to the unit commitment problem (McGuire, 1996) which describes the difficulties that the system operator faces in deciding which generating unit should be operated and at what level. There are two reasons why economic dispatch of different units may create controversies (Hirst & Kirby, 1997b). First, the operator may have different objectives, e.g., minimize price or minimize cost. When minimizing price, the system operator can often increase output of the price-setting unit to minimize its variable cost and the system price, even if it requires backing down the lower cost unit. On the other hand, when minimizing cost, outputs from individual units can swing dramatically as system load changes because the operator tries to bring on a new unit as demand rises and the new unit becomes the price-setter and is in fact operated at full load to minimize the price. Second, artificial requirements, such as "must-run" nuclear and hydro units in California, artificially suppress the market price for energy by forcing more expensive units online. For both reasons, even with close central coordination by the utilities today and significant efforts to use OR modeling tools, a significant amount of human judgement is required to operate the complex system.

In a market setting, the complexity of the system and mandated redispatches of energy will continue to plague the system operators. Citing a simple example, researchers (Hirst & Kirby, 1997b) have shown that:

> In principle, the system operator should be allowed to move generators up or down at cost to facilitate reliability. This may prove difficult to implement. If

> moving a generator would change its bid price to supply energy, this could increase what would otherwise have been the market price for energy. While the unit that was moved may be indifferent to this change, the other units will want to see the higher price established as the market clearing price. The system operator may be required to demonstrate that the shift in generator output was required exclusively for reliability. [emphasis added]

In a similar manner, the growing use of the ancillary service of dynamic scheduling must be demonstrably consistent and defensible. The goal of dynamic scheduling is to increase customer choices and promote competition by enabling the electronic transfer from one control area to another of the time-varying electricity consumption associated with a load or the time-varying production associated with a generator (Hirst & Kirby, 1997a). Examples of dynamic scheduling show that decisions made by the operators produce feedback effects in the complex network and therefore, customers are likely to demand that the decisions be justifiable, i.e., consistent, and defensible.

In both examples above, the need to justify decisions (voice) became important when the complexities of the electric system made decision-making a non-monotonic process, i.e., where a decision at one point of time created the context for decision-making at the subsequent point of time. Further, given the complexity of the system, use of the conventional algorithmic approaches were shown to require significant expert judgement. For both reasons, AI-based representation methods may be useful in augmenting the conventional methods of analysis and management - shown by a detailed example below.

Justifying ESCO Management Decisions

In essence, ESCO managers are like public representatives. They make important decisions on behalf of the public that hires them to represent their interest, i.e., to obtain energy and related services. Performance-based contracts define their responsibilities and typically, the primary measure of performance is a reduction in energy rates. PBR-based contracting is in vogue, with funding from federal government to promote the concept at the state and local levels (http://www.ornl.gov/EFP/).

With increasing demands of a competitive market and direct access to retail consumers in several states, the demands on the ESCO managers will also increase rapidly. To stay competitive, not only will they have to obtain good rates for their customers, but they will also have to present justification and convince their customers that the decisions they make in the process are consistent. Providing justifications for decisions and actions taken on behalf of CPR users may not be easy. In fact, the ability of public service agencies and companies to interface with their customers is typically poor because of the onerous burden of providing clear explanations to the public. One of the major reasons for the recent lack of interest in the ESCO industry is not just the stiff competition (exit for customer), but the public relations time lag and burden in convincing the scrutinizing customers (with voice) about the decisions being made on their behalf. As noted earlier, both exit and voice are important and whereas the effective mechanism for exit is competition between ESCO managers, there is no formal and practical mechanism for voice.

While most of the decisions made by the ESCO manager will be based on a formal financial comparative cost-benefit analysis of options, their customers would typically expect to see a simple explanation of their decisions. Further, discriminating customers will want to obtain better services in addition to better rates. Better services may be defined by better accommodation (a convenience, quality, and management of risk), a reduced potential for regret when conditions change, and reduced transactions costs.

One method of developing such explanations is by developing qualitative rules of thumb and conducting an AI based qualitative analysis of retail options. A published set of heuristics (Hadley & Hillsman, 1995) provide a good starting point for such an analysis. Table 6 below (Hadley & Hillsman, 1995) shows the relative values of electric customer options with regard to price, transactions cost, accommodation cost of customer desires, and potential for regret. The rankings of the various options are qualitative and relative. Furthermore, the heuristics are tentative, i.e., new information may change the rules themselves.

In the subsections below, first the knowledge base structures are discussed followed by the implementation of the rules of thumb as action rules and non-monotonic rules. Subsequently, the control strategy, inference mechanism, and user interface are described. Further, an example of the system's use is demonstrated. Finally, Appendix B provides an overview of the Symbolics XL 1201 programming environment and the basic constructs of KEE™, the AI system development shell used to implement the prototype is described below.

Table 6 : Relative Values of Retail Electric Options

		Price of Service	Transactions Cost	Accommodation Cost	Potential for Regret
Procurement Options	Self-generation	Low-medium	High	Medium-High	Medium-high
	Self-service Wheeling	Low-medium	High	High	Medium-high
	Alternate Carriers	Low	Medium-high	Low	Low-high
	DSM or Energy Services	Low-high	Medium	Low	Low-medium
	Relocation	Low-medium	High	Low	High
	Purchase	Low-high	Low-high	Low-high	Low-high
Purchase Options	Local Utility	Low-high	Low	High	Low-high
	Municipalization	Medium	High	High	Medium-high
	Bilateral Contracts	Low-medium	Medium	Low	Low-high
	Broker	Low-medium	Low-medium	Low-Medium	Medium
	Wholesale Poolco	Low-medium	Low	High	Low-medium
	Customer Owned	Medium	High	Medium-High	High
Pricing Options	Cost-based	Low-high	Low	Medium-High	Low
	Performance-based	Medium	Low	Medium-High	Low
	Time-of-Use	Low-medium	Medium-high	High	Low-medium
	Negotiated	Low-medium	High	Low-Medium	Low

Source: Adapted from (Hadley & Hillsman, 1995)

Knowledge Base Structures

The graph of units shown in Figure 7 shows the hierarchy of structures in the ESCO knowledge base. The unit hierarchies defined by slots and their facets are in Table 7 through Table 10. Information in the knowledge base structures is manipulated by rule bases for the specific condition defined by the user. An additional unit "selection-policy" defines values of slots of "retail-options" that define acceptability by the ESCO manager.

Figure 7 : Hierarchy of Unit Structures in the ESCO KB

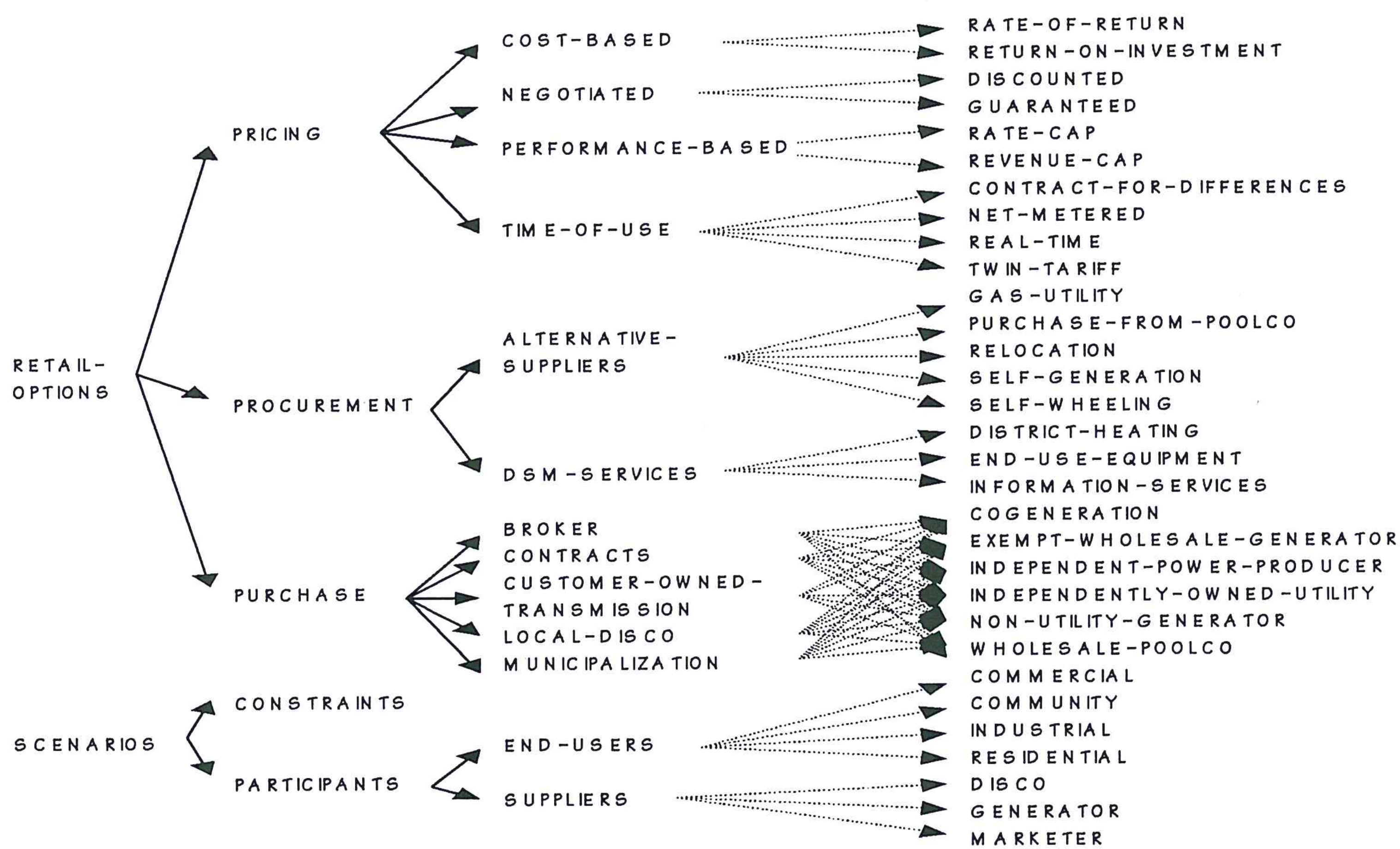


Table 7 : Level 1 Units and Slots

PARENT KB	LEVEL 1 UNIT	slot	valueclass	min	max	comment
ESCO KB	RETAIL-OPTIONS					
		accommodation	low medium high	1	2	convenience, quality of service, and management of risk
		potential-for-regret	low medium high	1	2	if the option selected is not correct
		price-of-service	low medium high	1	2	need low price and high efficiency
		transaction-cost	low medium high	1	2	efficacy of the retail option
	SCENARIOS					
		likelihood	likely probable improbable unlikely	1	1	of the scenarios occurring

Table 8 : Level 2 Units and Slots

LEVEL 1 PARENT	LEVEL 2 UNIT	slot	valueclass	min	max	comment
RETAIL-OPTIONS	PRICING					
accommodation		billing	lumpsum itemized	1		how easy or complex or transparent is the price
potential-for-regret	PROCUREMENT					
price-of-service		goal	energy-efficiency price exit negotiation self-reliance flexibility reliability			
transaction-cost	PURCHASE					
		availability	typical few unique			is there precedence
SCENARIOS	CONSTRAINTS					
likelihood		commodity-market	absent retail wholesale	1	1	availability for customers and suppliers
		gas-availability	end-use generation	1	1	in quantity, pressure, and quality for end use or for electricity generation
		gas-price	low medium high	1	2	projected
		investment-climate	favorable uncertain adverse	1	1	low inflation is favorable
		new-technology	distributed-generation retrofit process-control communications interconnection			expected and commercialized
		retail-access	fast slow			how quickly a competitive market will be established
		stranded-cost-	fast slow			how quickly it will be recouped
		US-state		1	1	
		wheeling-access	fast slow			on existing transmission lines
		wholesale-access	fast slow	1		retail or wholesale
	PARTICIPANTS					
		interaction	cooperative adversarial			between end users and suppliers

Table 9 : Level 3 Units and Slots

LEVEL 1 PARENT	LEVEL 2 PARENT	LEVEL 3 UNIT	slot	valueclass	min	max	comment
RETAIL-OPTIONS	PRICING	COST-BASED					
accommodation	billing	NEGOTIATED					
potential-for-regret		PBR					
price-of-service		TIME-OF-USE					
transaction-cost	PROCUREMENT	ALTERNATIVE-SUPPLIERS					
	goal	DSM-SERVICES					
	PURCHASE	BROKER					
	availability	CONTRACTS					
		CUSTOMER-OWNED-TRANSMISSION					
		LOCAL-DISCO					
		MUNICIPALIZATION					
SCENARIOS	CONSTRAINTS						
likelihood	commodity-market						
	gas-availability						
	gas-price						
	investment-climate						
	new-technology						
	retail-access						
	stranded-cost-recovery						
	US-state						
	wheeling-access						
	wholesale-access						
	PARTICIPANTS	END-USERS					
	interaction		aggregation	low medium high	1		
			behavior	proactive reactive resistent			expected pattern vis a vis energy efficiency
			commitment	low medium high	1	1	to manage
			consumption	retail wholesale	1	1	large of small
			risk-taking	prone averse	1	1	
		SUPPLIERS					
			behavior	proactive reactive passive resistent	1	1	response to change for consumer benefit

Table 10 : Level 4 Units and Slots

LEVEL 1 PARENT	LEVEL 2 PARENT	LEVEL 3 PARENT	1	2	3	4	5	6
RETAIL-OPTIONS	PRICING	COST-BASED	RATE-OF-RETURN	ROI				
accommodation	billing	NEGOTIATED	DISCOUNTED	GUARANTEED				
potential-for-regret		PBR	RATE-CAP	REVENUE-CAP				
price-of-service		TIME-OF-USE	CFD	NET-METERED	REAL-TIME	TWIN-TARIFF		
transaction-cost	PROCUREMENT	ALTERNATIVE-SUPPLIERS	GAS-UTILITY	PURCHASE-FROM-POOLCO	RELOCATION	SELF-GENERATION	SELF-WHEELING	
	goal	DSM-SERVICES	DISTRICT-HEATING	END-USE-EQUIPMENT	INFORMATION-SERVICES			
	PURCHASE	BROKER	COGENERATOR	EWG	IPP	IOU	NUG	POOLCO
	availability	CONTRACTS	COGENERATOR	EWG	IPP	IOU	NUG	POOLCO
		CUSTOMER-OWN-TRANSMISSION	COGENERATOR	EWG	IPP	IOU	NUG	POOLCO
		LOCAL-DISCO	COGENERATOR	EWG	IPP	IOU	NUG	POOLCO
		MUNICIPALIZATION	COGENERATOR	EWG	IPP	IOU	NUG	POOLCO
SCENARIOS	CONSTRAINTS							
likelihood	commodity-market							
	gas-availability							
	gas-price							
	investment-climate							
	new-technology							
	retail-access							
	stranded-cost-recovery							
	US-state							
	wheeling-access							
	wholesale-access							
	PARTICIPANTS	END-USERS	COMMERCIAL	COMMUNITY	INDUSTRIAL	RESIDENTIAL		
	interaction	aggregation						
		behavior						
		commitment						
		consumption						
		risk-taking						
		SUPPLIERS	DISCO	GENERATOR	MARKETER			
		behavior						

Control Strategy

The flow of control in the ESCO knowledge base is as follows.

1. The user is presented with a screen to define the local situation. Using buttons, the user asserts values into various units to define the background scenario which defines the existing situation.
2. The user presses the "GO" button to fire rules in the knowledge base to create possible scenarios.
3. The user chooses a scenario (world) and presses the "SELECT" button to pick a set of slots in "selection-policy" and chooses instances of "retail-options" that meet the policy criteria.
4. At any time, the user can press the "WHY" button to bring up a graph depicting the decision-making process, explaining how the rules are applied.
5. The user can select the facts of deductions in specific worlds, modify them, and press the "SELECT" button to re-run rules and assess the impact on the selections.

The simple control strategy hides a deceptively sophisticated process in the background. The ESCO manager may choose to make a decision at a point in time and based on additional information, change the decision at a later point in time. The impact of the change and the causal mechanisms leading to the impact are not always obvious in complex and incomplete situations with many heuristics. The ESCO knowledge base tracks the entire process and thereby enables the ESCO manager to demonstrate the consistency to the CPR users even when previously asserted facts have to be retracted in light of new information. With a simple control strategy, CPR users can voice their queries to the ESCO manager who, with the capability of explanation provided by the ESCO knowledge base, can respond with little effort.

Representation of Heuristics

As noted in Appendix A, the rule base development facilities in KEE™ enable the implementation of three types of rules. Table 11 below summarizes and compares the three rule types and their usage in the ESCO knowledge base.

Table 11 : Rule Types in the ESCO KB

	Action Rules (same.world)	**Action Rules (new.world)**	**ATMS Rules (all worlds)**
Form	IF <antecedent> THEN <consequent>	IF <antecedent> THEN IN.NEW.WORLD <consequent>	IF <justification> THEN DEDUCE <conclusion>
Generic Function	Asserting New Facts in Same Context	Asserting New Facts into New Contexts	Assert & Retract Facts per Logical Dependencies
Use in ESCO	Characterization of Retail-Options	Maintaining Feasible Scenarios	Pruning Search Space with Constraints

Rules also are grouped into rule classes to facilitate focussed application to specific problem types. Within the rule classes, the three types of rules above are usually separated into three subclasses. Generally, action rules in ESCO are more definitive and focussed than ATMS rules, which prune the search space of solutions by asserting assumptions using theorems about contexts that are inconsistent and not feasible.

The knowledge base consists of the following rule classes.

1. The "selection.policy" rule is an individual ATMS rule. It simply states that

   IF ((the accommodation of an.instance.of retail-options is less than the desired.accommodation of selection.unit) AND

   ... Repeat for potential-for-regret, price-of-service, and transaction-cost slots ...)

   THEN DEDUCE FALSE.

   The rule assigns a "nogood" status to those context worlds which have retail-options with unacceptable characteristics. In this manner, impacts of the acceptability criteria set in policy are set up as dependents. When the criteria change, the impact will be propagated and tracked by the ATMS.

2. All rules to generate new scenarios are grouped as "scenario.rules", e.g.,

   - IF ((the commitment of industrial.end-users is high) AND

     (the risk-taking of industrial end-users is prone) AND

     (the behavior of suppliers is (reactive OR proactive)) AND

     (the interaction of participants is (NOT adversarial)))

   THEN IN.NEW.WORLD

     (the transactions-cost or retail.options is low)

   - IF ((retail-access is fast) AND

     (investment-climate is favorable) AND

     (new-technology is (communications AND interconnection)))

THEN IN.NEW.WORLD

(price-of-service of net-metered is low)

- IF ((commodity-market is wholesale) AND

  (wholesale-access is fast) AND

  (wheeling-access is slow) AND

  (retail-access is fast) AND

  (aggregation of community is high))

  THEN IN.NEW.WORLD

  ((accommodation of municipalization is high) AND

  (price-of-service of municipalization is low))

Each firing of a new.world.rule adds the new conclusion into a new context. The new world (context) is dependent on the facts already in the earlier contexts. If at a future time, a previous context is found to be "nogood" (inconsistent), the new.world also will become "nogood".

3. All specific technology related rules are grouped as "technology.rules", e.g.,

   - IF (the goal of procurement is energy-efficiency)

     THEN (the potential-for-regret of DSM-Services is low)

   - IF (the billing is itemized)

     THEN (the accommodation of time-of-use is high)

   - IF (availability of purchase-option is few)

     THEN (transaction-cost of cogenerator is high)

The same.world rules apply in the current world, i.e., in whichever world the reasoning is focussed at the time they are fired. They also can be specified to act in specific worlds. As the monotonically added facts cannot be withdrawn, any additional facts that conflict with the existing facts will make the context inconsistent and the world "nogood". Therefore, the same.world rules are usually constructed based on premises whose values will not change - or at least there is little uncertainty about the values of the premises.

As such, there is no conflict at all between the qualitative reasoning implemented currently in the ESCO knowledge base and quantitative models, which perform cost-benefit analysis of various alternatives. In fact, results of quantitative models can be used within the ESCO knowledge base and tempered with the heuristics - as experts do.

Exemplary Use of System

Appendix C presents a screen by screen walkthrough of a simple demonstration case of the use of ESCO in a non-monotonic process. In addition to showing the capabilities of the AI approach in a Symbolics and KEE environment, the use of non-monotonic representation is shown when previously made assertions are retracted from the knowledge base. Two types of lessons were learned in the process of developing the ESCO knowledge base: operational and theoretical.

Operational Lessons

The operational lessons learned were primarily in the development and implementation of the ESCO KB to assist in the design of policy.

Operational Lessons

The operational lessons learned were primarily in the development and implementation of the ESCO KB to assist in the design of policy.

1. The amount of knowledge, which can be obtained from existing references for creating a knowledge base, is large. Converting the knowledge into heuristics and then into KB rules requires knowledge of the domain and experience with the process of developing AI systems. The complexity of knowledge bases, and especially the large search spaces generated by heuristics, clearly shows the difficulty that CPR participants may have in ensuring that the decision process is consistent and defensible. Without a formal tool to maintain consistency and defensibility in the complex process, the voice mechanism for retail customers is likely to be ineffective.
2. The exercise of discriminating between standard rules, new.world.action rules, and ATMS rules provides a structured means of clarifying what is precisely important to the CPR participants. In particular, the formulation of ATMS rules makes the desires of the retail customers specific, in terms of which assumptions are important and which assumptions the ESCO manager must track carefully. The conditions specified in the ATMS rules are the ones where the retail customers are likely to express their concerns (voice).
3. KEE's ATMS is capable of justifying its conclusions in the non-monotonic reasoning path followed during a session. By its interaction with KEEWorlds™ facility, the ATMS can track and explain changes across scenarios presented by the user. Using

the non-monotonic representation, the CPR participants can ensure that the decision making process is consistent and defensible.

4. CPR participants, who have to be able to justify their decisions from time to time, can benefit greatly by documenting their decision process with a non-monotonic system. The non-monotonic system also may be useful in playing "what-if" analysis to compare various alternatives a-priori.

Theoretical Lessons

The main theoretical lessons learned during the development of the ESCO KB are concerning the role of non-monotonic systems for CPR institutional design.

1. It is not meaningful to track changes in all variables using the ATMS. The selection of which changes need to be tracked using the ATMS is domain specific.
2. The ATMS provides a unique method of representing non-monotonic decision making processes in CPR institutions. ATMS based decision making processes can impart consistency and defensibility to the process, and in turn, provide a formal voice mechanism to CPR participants.
3. Verification and validation of AI systems is inherently difficult. The main problem lies in the basic intent of AI processes - to model incomplete systems. As such systems are not designed to provide optimal solutions, the problem is similar to that of deciding which expert is better. However, it is the contention of AI modelers that it is only in difficult problems that one requires an expert's judgement and typically in such problems, there are only a few experts.

CHAPTER 7

CONCLUSIONS

Retail institutions evolving in the ongoing spate of restructuring efforts will have some characteristics of a common property resource. In a competitive environment, the participants can choose between several CPR managers in the market, thereby providing an exit mechanism to the consumer. On the other hand, the process by which retail customer voice is exercised is public participation, in which customers can scrutinize the decision making process used by the CPR managers.

Due to systemic uncertainties and incomplete knowledge, the decision making process must be flexible so that the CPR manager can revise decisions based on new information. The flexibility introduces path dependencies and therefore, the decision making process is non-monotonic. Such non-monotonic decision processes cannot be modeled easily with conventional monotonic systems. Therefore, non-monotonic actions made by the CPR manager cannot be explained with the use of a conventional monotonic system.

The primary unique contribution of this research is the design, development, and demonstration of a useful representation of the CPR institutions using an artificial intelligence based model, which supports non-monotonic reasoning and scenario evaluation. The contribution to theory is the demonstration of a powerful AI based methodology for representing and modeling alternative designs of institutions and their policies. An exemplary demonstration of the prototype built in this research, to model the non-monotonic decision process of ESCO managers, confirms the utility of non-monotonic logic in institutional design. Other applications need to be researched. Specific conclusions follow.

1. In the electric industry, restructuring is expected to lead to a decentralized competitive market with direct access to the retail customer. From the poor performance of the industry as a regulated regional monopoly, the competitive model is expected to provide greater customer choice and an exit mechanism (FERC888, 1996). With "lazy monopolies," it is important to balance (Hirshman, 1970) the exit mechanism with a complementary voice mechanism, which can assist the industry from lapsing into a pattern of steady deterioration.
2. With features like other network industries of a CPR institution (Ostrom, 1992), the electric industry is subject to path-dependence (Rosenberg, 1994), especially at the retail level. Decision making by CPR participants is made complex by other uncertainties, such as rapid technological change (Levin, 1997). Path-dependencies are managed in practice using a non-monotonic decision process which allows incremental retraction and modification of previously made assertions as more information is obtained.
3. It is difficult to design an effective voice mechanism for a complex decision making environment because the decision making process is non-monotonic and therefore, inherently difficult to explain to the customers. Yet, to be an effective

recuperative mechanism, the non-monotonic decision making process must be defensible in response to customer concern (public scrutiny) about poor performance (voice).

4. Formal voice mechanisms for retail markets should be designed with the appropriate representation (conceptualization) of the resulting decision process.
5. Exemplary scenarios in coordinated multilateral trading, dynamic scheduling and dispatch, and ESCO decision making warrant the need for a formal model of the non-monotonic decision making process for the design of a voice mechanism. The decision making process can be defensible and justifiable if it is consistent. In all cases, the customers demand explanations from the providers about the decisions made on their behalf in obtaining their supply of electricity.
6. Artificial intelligence based models, with an assumption-based truth maintenance system, provide the tools to represent non-monotonic decision making processes (Filman, 1988). A prototype application in ESCO decision making verifies the potential use of AI and ATMS techniques in maintaining consistency in non-monotonic decision processes.
7. As a generic policy related conclusion, it is seen that non-monotonic models can be used to design a voice mechanism to complement the exit mechanism provided by decentralized, competitive markets. In particular, network industries facing significant technological changes, such as telecommunications and water, are potentially good candidates for non-monotonic modeling.

8. Where knowledge about a system is incomplete, policy makers should institute mechanisms to capture and model expert judgement in an AI-based knowledge base. The effort spent in building knowledge bases can be useful in assuring the retail customers (public participants) about the consistency and defensibility of decisions made particularly in the context of technological uncertainties.

Future research directions from this research include the following.

- Extend the application of non-monotonic logic based AI systems to model other CPR institutions - for coordinated multilateral trading, dynamic scheduling and dispatch operations in the electric utilities - to derive a generalized representation of CPR institutions.
- Design non-monotonic systems which can model the arbitrage opportunities for water, gas, electric, cable, and telecom utilities converging their operations to provide a one-stop-shop of diverse utility services. The converged utilities may be able to use non-monotonic systems to design customer specific service packages - leading to a National Information Infrastructure in the future.
- Research the role of non-monotonic systems to model and manage other path dependent processes, such as:
  - learning organizations and policy evolution,
  - sequences of spatial processes, such as technology diffusion.
- In the methodology area, evaluate the potential and use of a non-monotonic goal programming environment, using truth maintenance systems to manage the sequence of pre-emptive priorities.

GLOSSARY

ADICO	An institutional grammar consisting of ATTRIBUTES, DEONTIC, AIM, CONDITIONS, and OR ELSE components (Crawford & Ostrom, 1994) [see p. 89]
AI	Artificial Intelligence [see p. 88]
ART™	Automated Reasoning Tool developed by Inference Corporation, Los Angeles, CA.
ATMS	Assumption-based Truth Maintenance System (de Kleer, 1986) [see p. 94]
BPA	Bonneville Power Administration - a public power company which operates mainly in the Pacific Northwest.
CPR	Common Property Resource - economic goods and services characterized by high subtractibility and high cost of exclusion of non-payers (Ostrom et al., 1993) [see p. 50 and Table 3]
CIF	Pricing method of a product including its cost, insurance, and freight. [see Footnote 30]
C&F	Pricing method of a product including its cost and freight. [see Footnote 30]

DDB	Dependency Directed Backtracking - an efficient method used in a Truth Maintenance System for revising a previously made decision, which contributes to an inconsistency. [see p. 94]
DISCO	A power distribution company. Owns and manages the distribution system - a regulated monopoly for customers in states without direct access to competitive prices. Purchases and sells electricity. [see p. 38]
DoE	Department of Energy
DSM	Demand Side Management. Typically an energy conservation methodology used to modify and match customer's demand for power.
EPAct	The Energy Policy Act of 1992.
EPRI	Previously the Electric Power Research Institute in Palo Alto, CA. A research organization previously funded by taxing their electric utility members. With the emergence of a competitive market, the organization (now simply called EPRI) is rapidly changing into a contract research and consulting organization. (http://www.epri.org/)
ESCO	An energy service company. A highly competitive firm which sells diverse energy management solutions, including energy brokerage services, to meet customers' needs. [see p. 43]
EPA	Environmental Protection Agency
Exit	The exit option is exercised when the performance of an organization deteriorates. Some customers stop buying a firm's products or some members leave the organization. "As a result, revenues drop, membership

	declines, and management is impelled to search for ways and means to correct whatever faults have led to exit." (Hirshman, 1970, p. 4)
FERC	Federal Energy Regulatory Commission
FOB	Free on berth - pricing method of a product which includes its cost as delivered at the shipping berth. [see Footnote 30]
ISO	Independent System Operator. A regulated monopoly which dispatches and manages the sale of electricity across a regional transmission system. It does not own transmission assets. Dispatch choices may be limited by bilateral contracts and by must-run units specified in a merit order by the regulatory body. [see p. 44]
KEE™	Knowledge Engineering Environment developed by Intellicorp, Inc., Mountain View, CA.
NERC	National Electric Reliability Council
NOPR	Notice of Proposed Regulation
OPF	Optimal Power Flow
Order 888	FERC's NOPR (FERC888, 1996) to introduce competition in the electric industry per the EPAct.
Order 889	FERC's NOPR accompanying Order 888 to provide OASIS - an Internet based computer system for trading transmission rights with equal access per the requirements in Order 888.
PBR	Performance Based Rates - typically used in ESCO agreements.

PEX	Power Exchange - An complementary commodity market institution to the ISO. Uses various trading rules and algorithms to auction electricity. Some overlap with functions performed by independent scheduling coordinators who typically arrange bilateral trades (http://www.apex.com/)
PJM	Pennsylvania - (New) Jersey - Maryland pool.
Poolco	A regulated institution consisting of PEX and ISO.
PUC	Public Utility Commission
PUHCA	Public Utilities Holding Companies Act of 1935.
PURPA	Public Utilities Regulatory Policies Act of 1979.
REA	Rural Electrification Administration.
Symbolics™	A specialized tagged architecture Lisp machine made by Symbolics, Inc., Bedford, MA. The model used in this study is the Symbolics XL1201.
TMS	Truth Maintenance System (Doyle, 1979). [see p. 94]
TRANSCO	Transmission Company. Typically owns, plans, and manages the transmission system. As a regulated monopoly, it does not dispatch generation units and does not make markets. [see p. 37]
TVA	Tennessee Valley Administration - a public power company.
Voice	The recuperative mechanism of voice is exercised when an organization's performance deteriorates. Customers or members express their dissatisfaction directly or indirectly to the management (or other authority) or through general protest. "As a result, management once

again engages in a search for the causes and possible cures…" (Hirshman, 1970, p. 4)

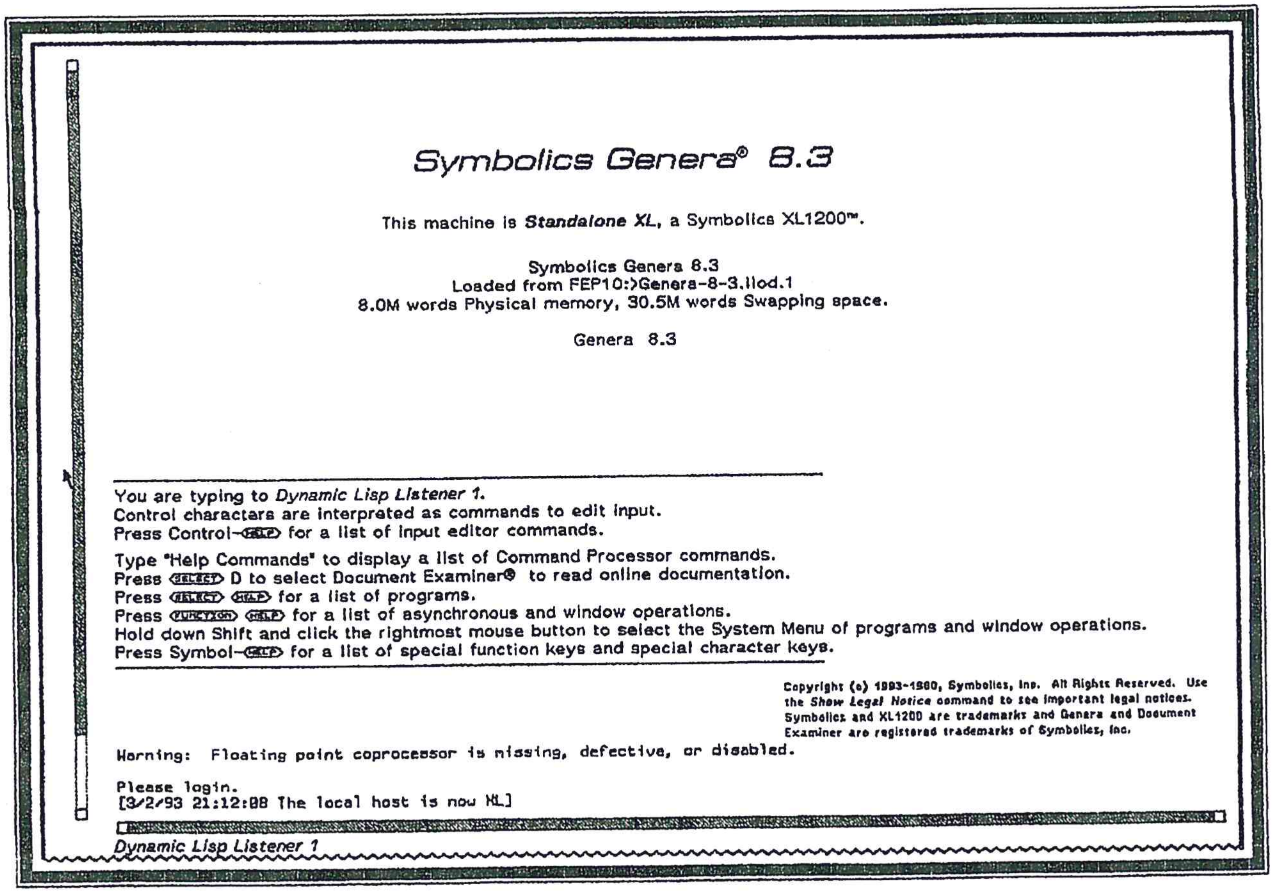
APPENDIX C.

DEMONSTRATION SCREENS OF ESCO KNOWLEDGE BASE

The figures below are captured directly from the screen to demonstrate the use of the ESCO knowledge base to model a non-monotonic decision process, where facts can be incrementally added and retracted during the decision process. Key features of the demonstration screens are provided with each figure below. Specific terms appearing on the screen figures are in SMALL CAP FONT.

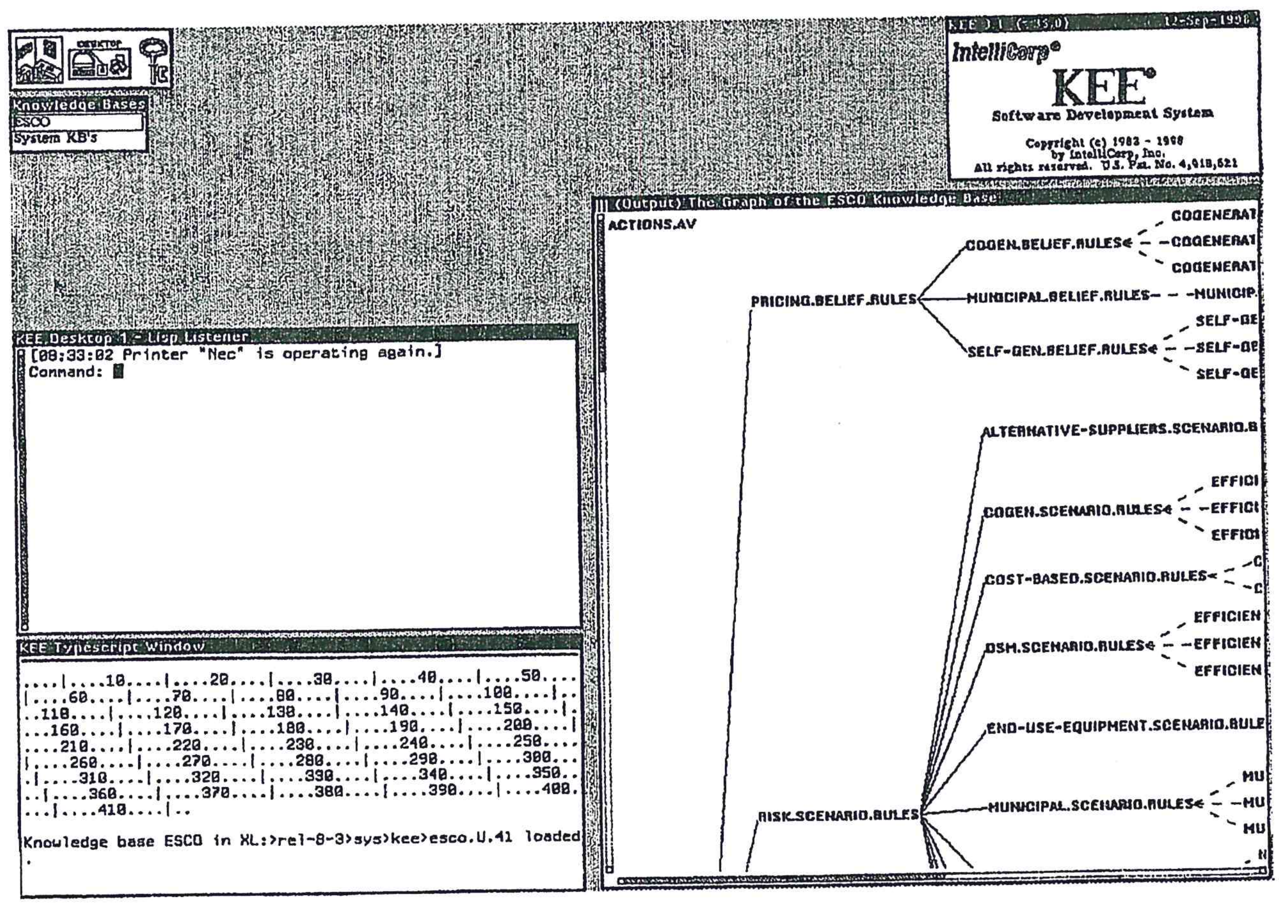
This is the start-up screen of the Symbolics XL 1201 used for developing ESCO, with the operating system Genera 8.3. The user is already in a full Lisp environment.

Figure C- 1: The Symbolics Environment



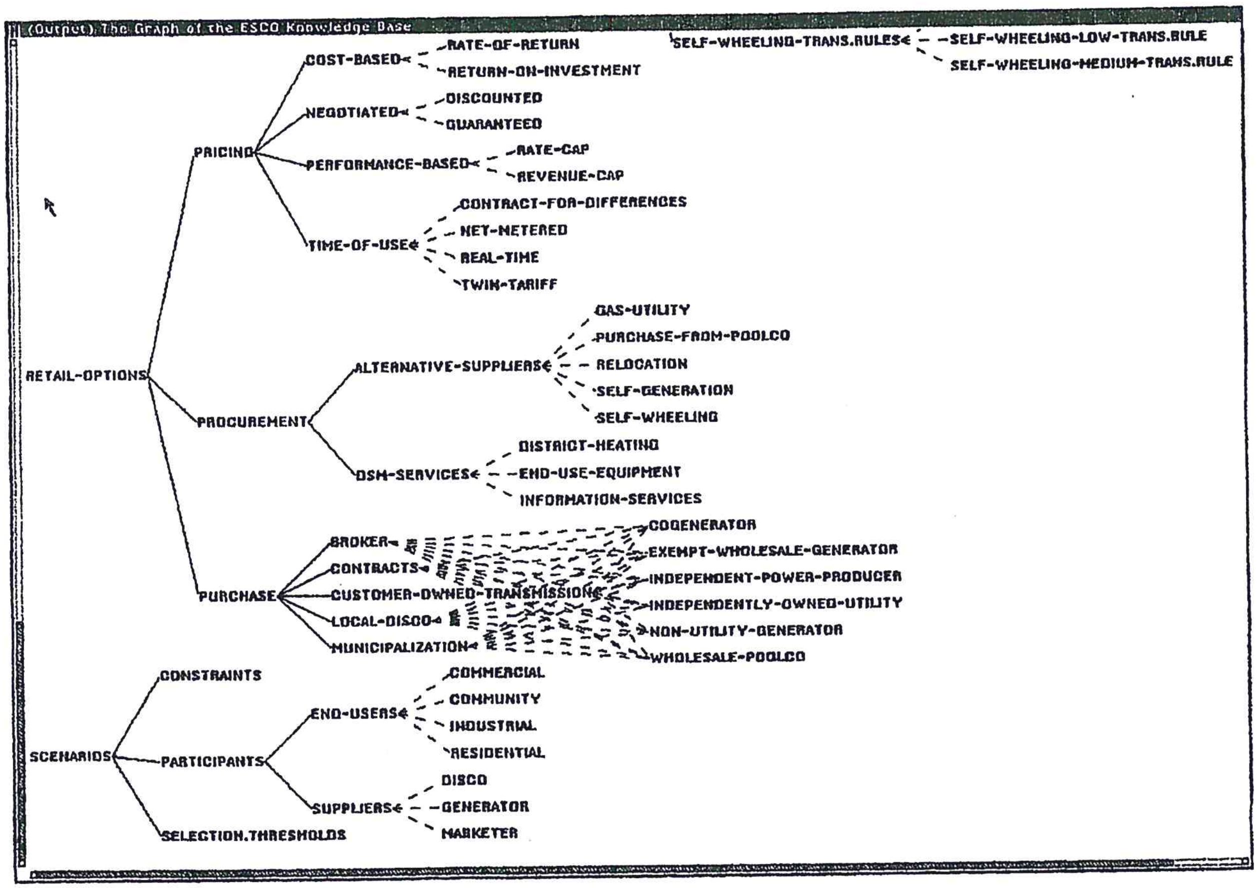
In KEE™, the ESCO KB (417 units) is loaded. The Lisp Listener window is for Lisp/KEE™ commands. The Typescript window is for KEE™ related I/O. Icons on the upper left enable user control. The user interacts via the output window.

Figure C- 2: The KEE and ESCO Environment



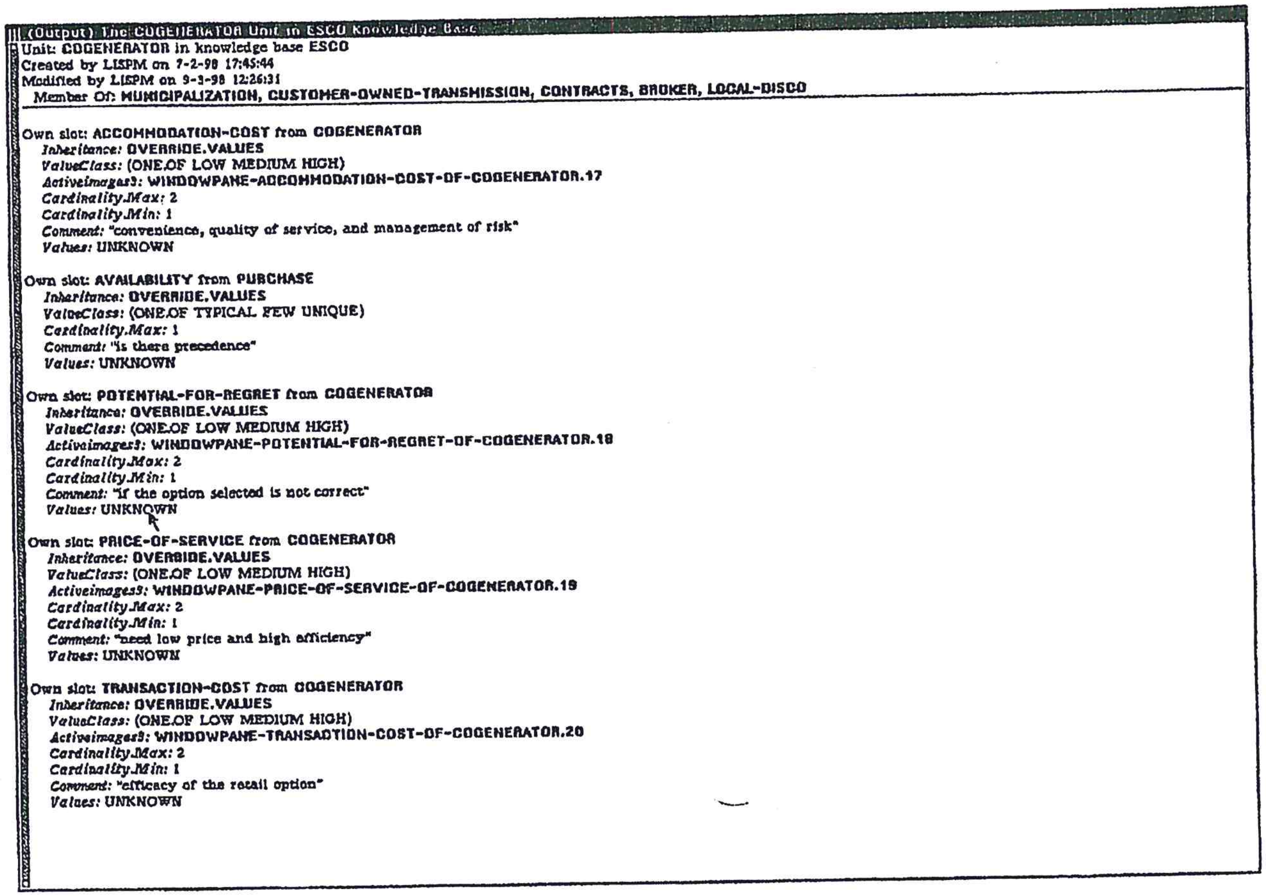
The ESCO KB has two hierarchies of units: RETAIL-OPTIONS and SCENARIOS. The solid and dashed lines in RETAIL-OPTIONS are "a-kind-of" and "is-a" relations. The solid and dashed lines in SCENARIOS are "a-part-of" and "is-a" relations.

Figure C- 3: Knowledge Base Structure of ESCO



Each unit is characterized by its slots. Slots are specified by how its values are inherited or derived, any attached images, allowable values, maximum and minimum number of values, and descriptive comments. Values are filled in during execution.

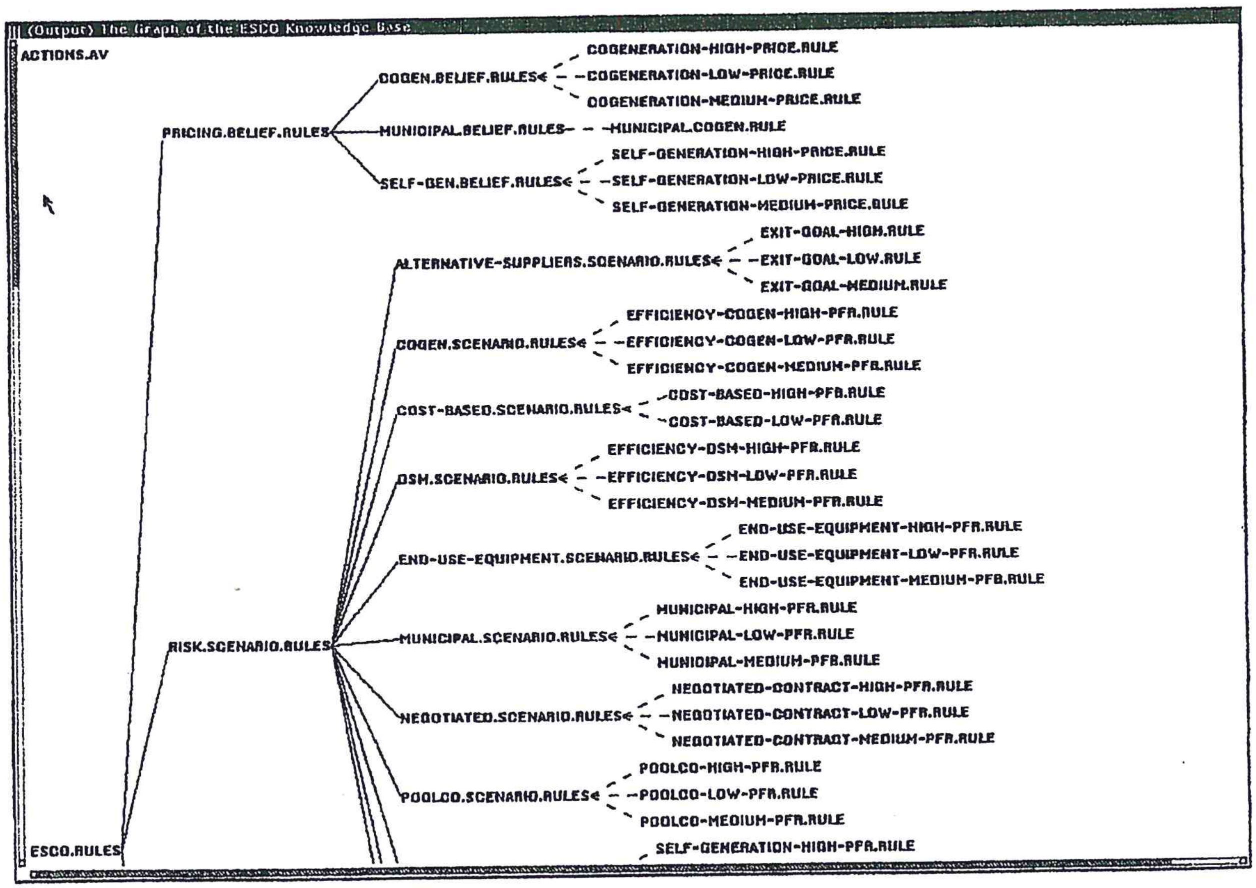
Figure C- 4: Sample Unit and its Slots



Rules are also represented as unit hierarchies. Belief rules are ATMS rules and scenario rules are new.world.action rules.

Solid lines represent "a-part-of" relations and dashed lines represent "is-a" relations.

Figure C- 5: Rule Classes in ESCO



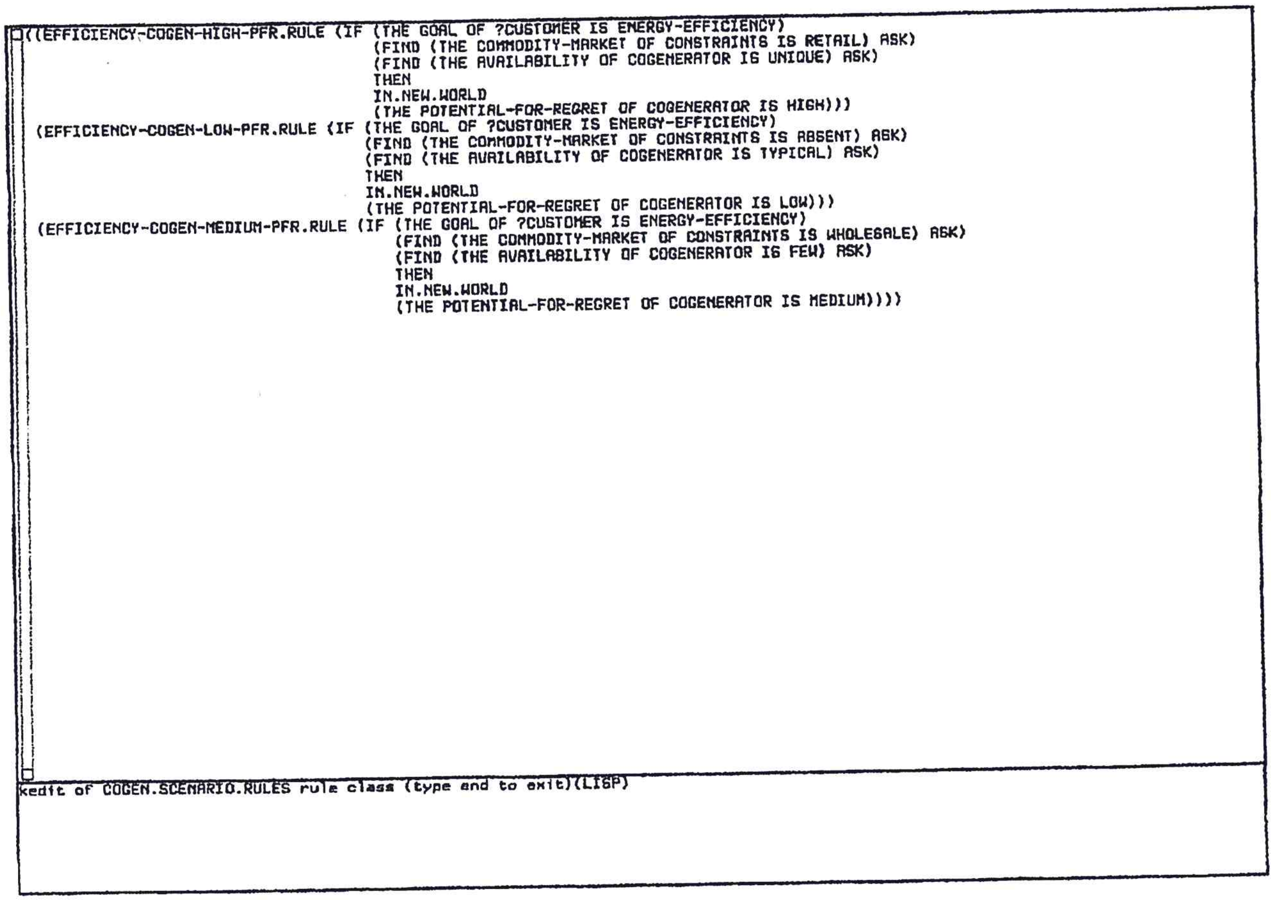
ATMS belief rules have the form: WHILE <antecedent> BELIEVE <consequent>. Belief rules maintain the logical relationship between <antecedent> and <consequent> sets. The ATMS tracks the sequence of application of belief rules.

Figure C- 6: Sample ATMS Belief Rules

```
((COGENERATION-HIGH-PRICE.RULE (WHILE (THE GAS-PRICE OF CONSTRAINTS IS HIGH)
                                      (THE NEW-TECHNOLOGY
                                           OF
                                           CONSTRAINTS
                                           IS
                                           DISTRIBUTED-GENERATION)
                                      (THE INVESTMENT-CLIMATE
                                           OF
                                           CONSTRAINTS
                                           IS
                                           ADVERSE)
                                      (THE AGGREGATION OF INDUSTRIAL IS LOW)
                                      (THE CONSUMPTION OF INDUSTRIAL IS RETAIL)
                                      (THE GAS-AVAILABILITY
                                           OF
                                           CONSTRAINTS
                                           IS
                                           GENERATION)
                                      BELIEVE
                                      (THE PRICE-OF-SERVICE OF COGENERATOR IS HIGH)))
 (COGENERATION-LOW-PRICE.RULE (WHILE (THE GAS-PRICE OF CONSTRAINTS IS LOW)
                                     (THE NEW-TECHNOLOGY
                                          OF
                                          CONSTRAINTS
                                          IS
                                          PROCESS-CONTROL)
                                     (THE INVESTMENT-CLIMATE
                                          OF
                                          CONSTRAINTS
                                          IS
                                          FAVORABLE)
                                     (THE AGGREGATION OF INDUSTRIAL IS HIGH)
                                     (THE CONSUMPTION OF INDUSTRIAL IS WHOLESALE)
                                     (THE GAS-AVAILABILITY
                                          OF
                                          CONSTRAINTS
                                          IS
                                          END-USE)
                                     BELIEVE
                                     (THE PRICE-OF-SERVICE OF COGENERATOR IS LOW)))
 (COGENERATION-MEDIUM-PRICE.RULE (WHILE (THE GAS-PRICE OF CONSTRAINTS IS MEDIUM)
                                        (THE NEW-TECHNOLOGY
                                             OF
                                             CONSTRAINTS
                                             IS
                                             PROCESS-CONTROL)
Kedit of COGEN.BELIEF.RULES rule class (type end to exit)(LISP)   [More below]
```

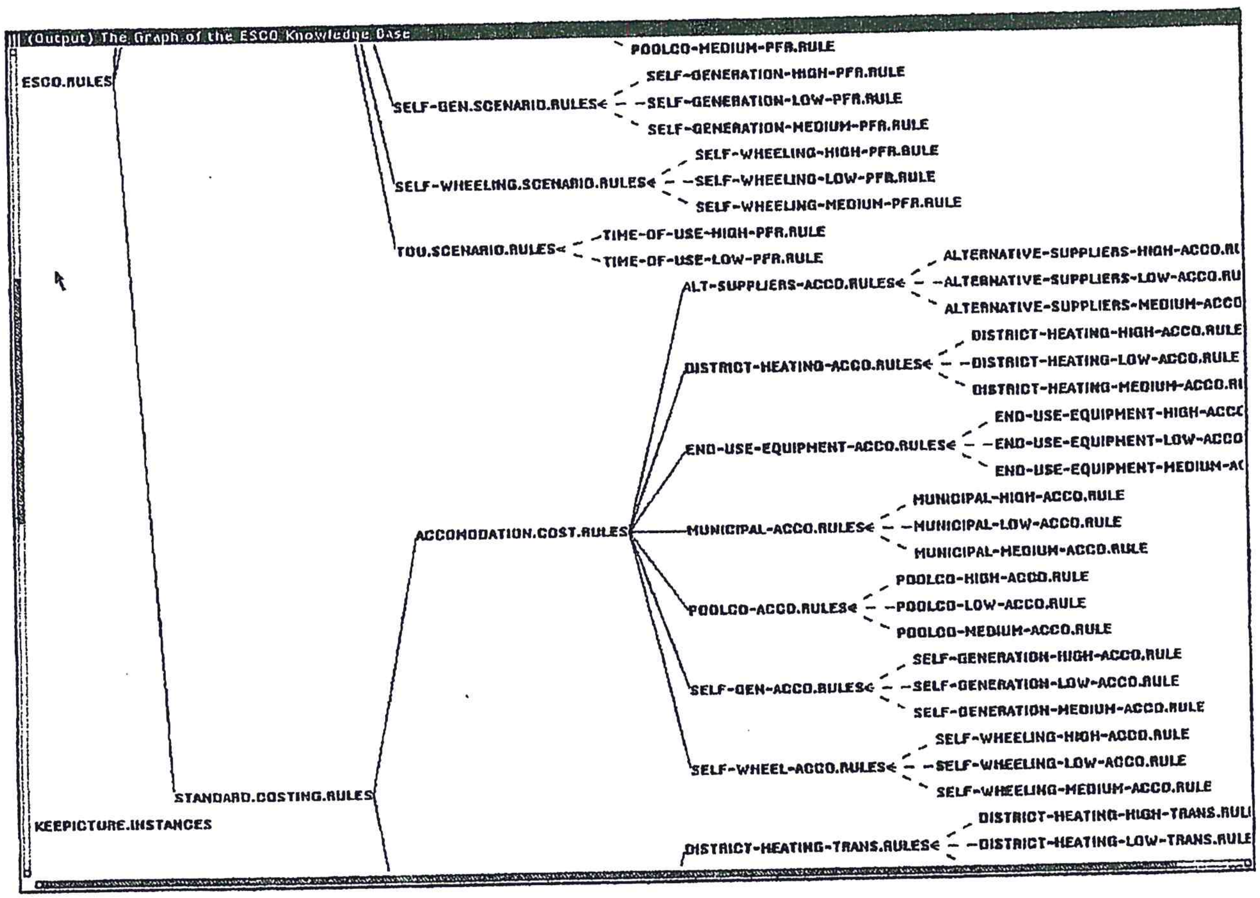
Scenarios are simulated with new.world.action rules: IF <consequents> THEN IN.NEW.WORLD <consequents>. When <antecedents> are met in a context (world), <consequents> are asserted in a derived context (child world).

Figure C- 7: Simulating Alternative Scenarios in Worlds



ESCO contains rules which apply within a world (context) to evaluate the accommodation (adaptation) cost of using different retail options.

Figure C- 8: Classes of Rules Which Act Within a World



The rules below are of the form IF <antecendents> THEN <consequents>. KEE™ provides many functions and operators, e.g., FIND starts backward chaining of other rules to prove its antecedent and ASKs the user if the search is not fruitful.

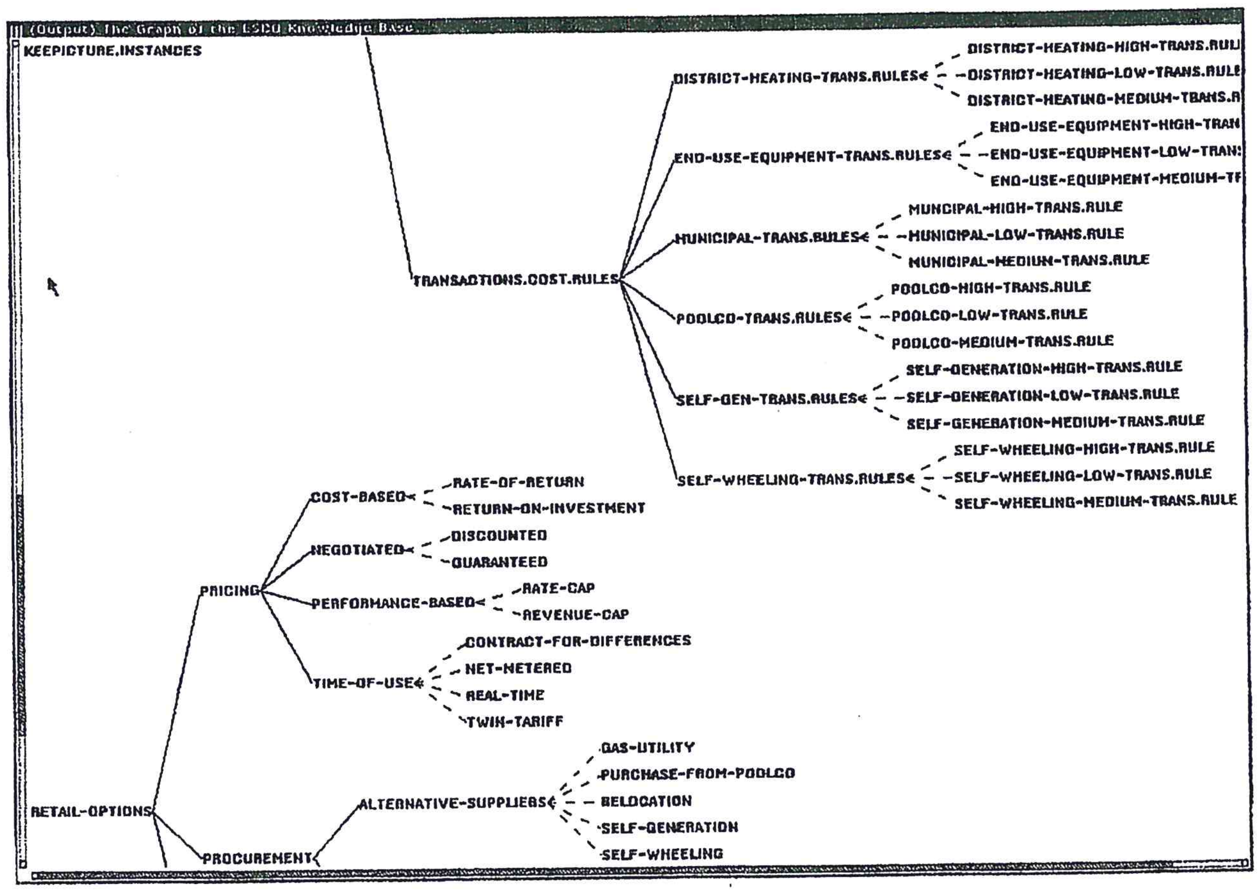
Figure C- 9: Some Simple Rules

```
((MUNICIPAL-HIGH-ACCO.RULE (IF (FIND (THE COMMODITY-MARKET OF CONSTRAINTS IS RETAIL) ASK)
                               (FIND (THE RETAIL-ACCESS OF CONSTRAINTS IS FAST) ASK)
                               (FIND (THE WHOLESALE-ACCESS OF CONSTRAINTS IS FAST) ASK)
                               THEN
                               (THE ACCOMMODATION-COST OF MUNICIPALIZATION IS HIGH)))
 (MUNICIPAL-LOW-ACCO.RULE (IF (FIND (THE COMMODITY-MARKET OF CONSTRAINTS IS WHOLESALE) ASK)
                              (FIND (THE RETAIL-ACCESS OF CONSTRAINTS IS SLOW) ASK)
                              (FIND (THE WHOLESALE-ACCESS OF CONSTRAINTS IS FAST) ASK)
                              THEN
                              (THE ACCOMMODATION-COST OF MUNICIPALIZATION IS LOW)))
 (MUNICIPAL-MEDIUM-ACCO.RULE (IF (FIND (THE COMMODITY-MARKET OF CONSTRAINTS IS RETAIL) ASK)
                                 (FIND (THE RETAIL-ACCESS OF CONSTRAINTS IS SLOW) ASK)
                                 (FIND (THE WHOLESALE-ACCESS OF CONSTRAINTS IS FAST) ASK)
                                 THEN
                                 (THE ACCOMMODATION-COST OF MUNICIPALIZATION IS MEDIUM))))

kedit of MUNICIPAL-ACCO.RULES rule class (type end to exit)(LISP)
```

ESCO also contains rules to estimate transactions costs of using different retail options. The hierarchy of function specific rule units allows the developer to add individual rules without affecting other rules - an advantage in incremental development.

Figure C- 10: Functional Rule Hierarchies



Sample rules below show that within rules, variables (such as ?ANY-END-USER) can be used to define more generalized rules.

Such rules are automatically bound to specific objects during the execution of the search process.

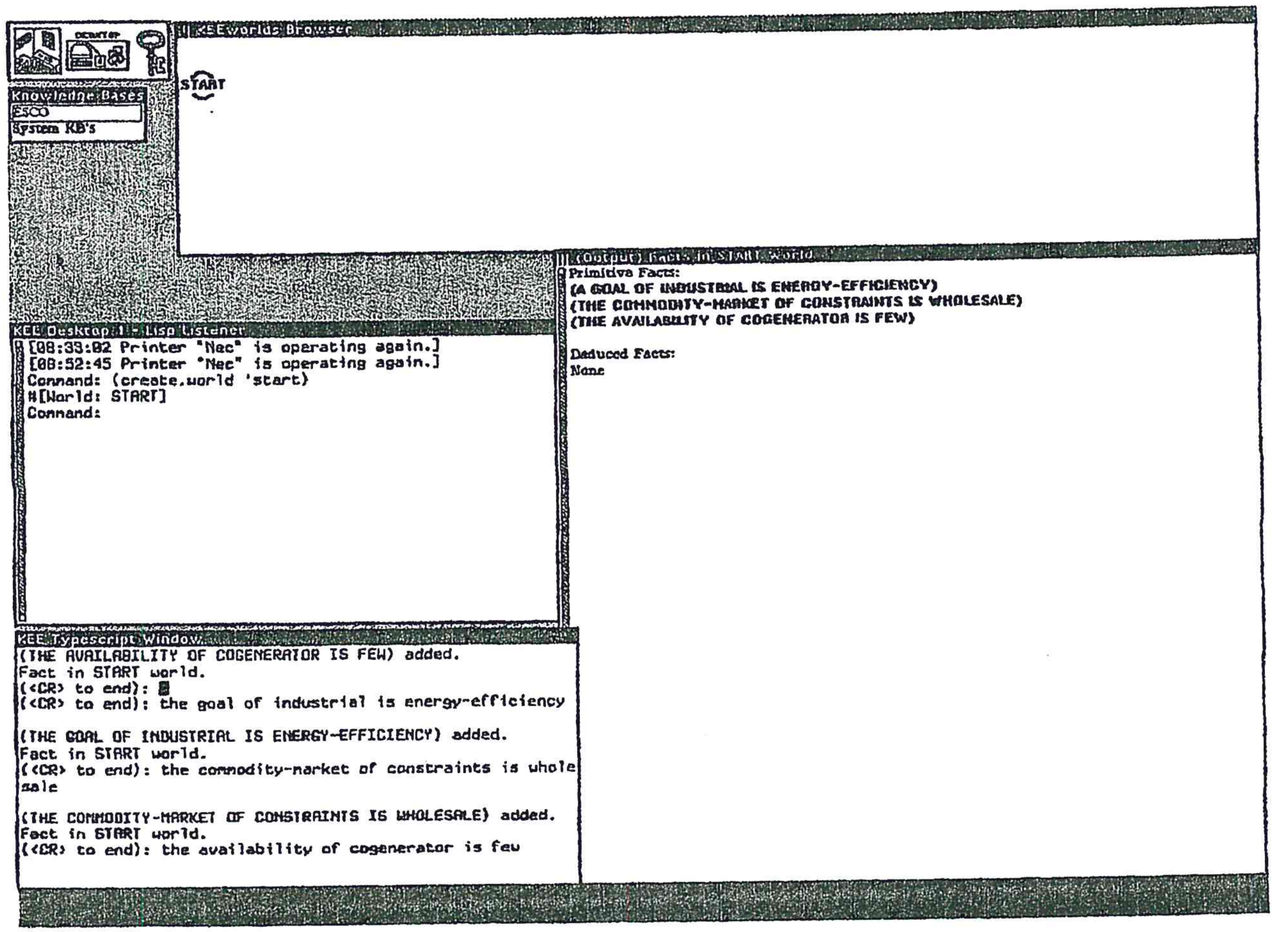
Figure C- 11: Variables in Rules

```
((MUNCIPAL-HIGH-TRANS.RULE (IF (?ANY-END-USER IS IN END-USERS)
                                (FIND.ANY (FIND (THE AGGREGATION OF ?ANY-END-USER IS LOW) ASK))
                                (FIND.ANY (FIND (THE CONSUMPTION OF ?ANY-END-USER IS RETAIL) ASK))
                                (FIND (THE STRANDED-COST-RECOVERY OF CONSTRAINTS IS FAST) ASK)
                                (FIND (THE AVAILABILITY OF MUNICIPALIZATION IS UNIQUE) ASK)
                                THEN
                                (THE TRANSACTION-COST OF MUNICIPALIZATION IS HIGH)))
 (MUNICIPAL-LOW-TRANS.RULE (IF (?ANY-END-USER IS IN END-USERS)
                                (FIND.ANY (FIND (THE AGGREGATION OF ?ANY-END-USER IS HIGH) ASK))
                                (FIND.ANY (FIND (THE CONSUMPTION OF ?ANY-END-USER IS WHOLESALE) ASK))
                                (FIND (THE STRANDED-COST-RECOVERY OF CONSTRAINTS IS SLOW) ASK)
                                (FIND (THE AVAILABILITY OF MUNICIPALIZATION IS TYPICAL) ASK)
                                THEN
                                (THE TRANSACTION-COST OF MUNICIPALIZATION IS LOW)))
 (MUNICIPAL-MEDIUM-TRANS.RULE (IF (?ANY-END-USER IS IN END-USERS)
                                   (FIND.ANY (FIND (THE AGGREGATION OF ?ANY-END-USER IS MEDIUM) ASK))
                                   (FIND.ANY (FIND (THE CONSUMPTION OF ?ANY-END-USER IS WHOLESALE) ASK))
                                   (FIND (THE STRANDED-COST-RECOVERY OF CONSTRAINTS IS SLOW) ASK)
                                   (FIND (THE AVAILABILITY OF MUNICIPALIZATION IS FEW) ASK)
                                   THEN
                                   (THE TRANSACTION-COST OF MUNICIPALIZATION IS MEDIUM))))
```

```
kedit of MUNICIPAL-TRANS.RULES rule class (type and to exit)(LISP)
```

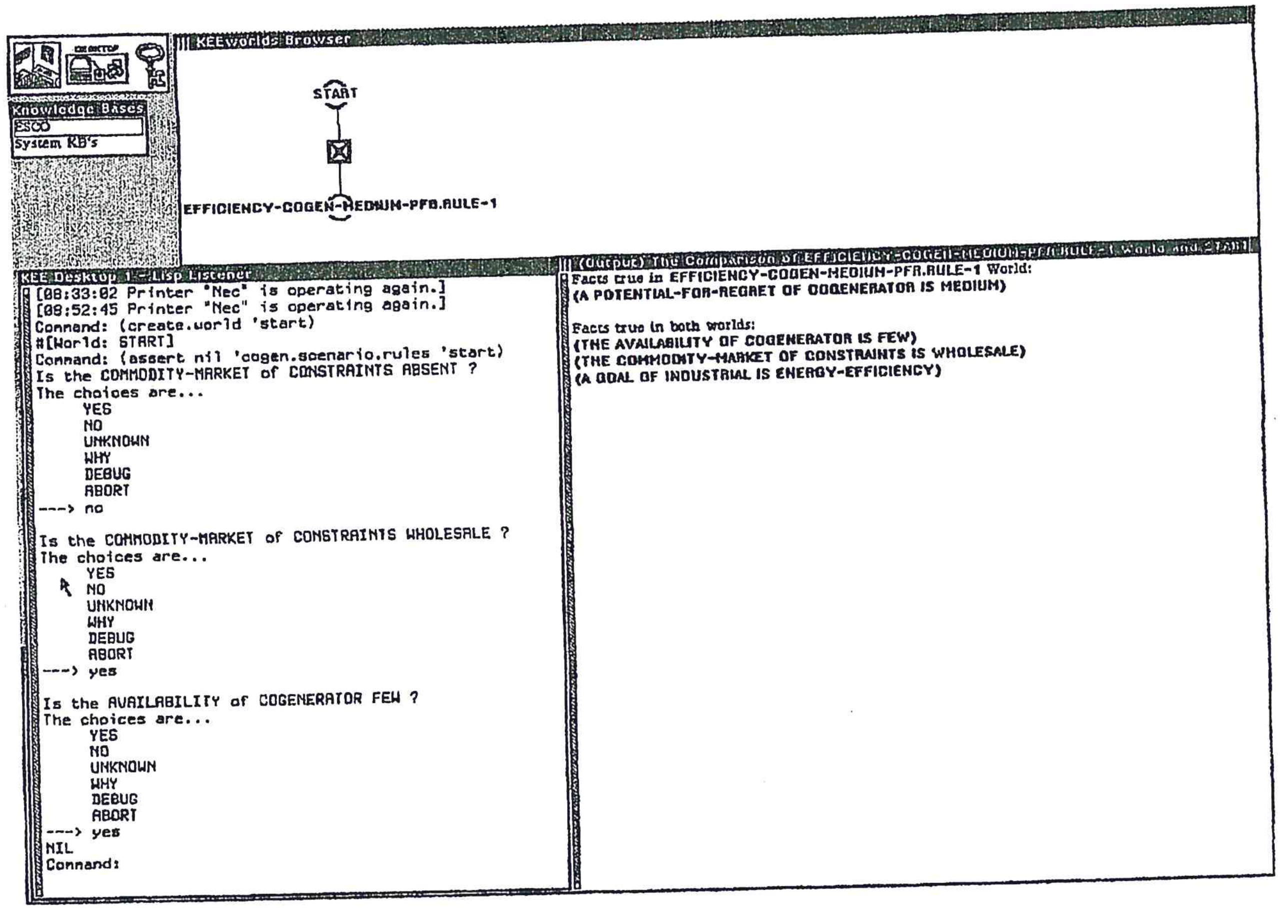
To begin the interaction, the world START is created in the Lisp Listener by the user and facts are asserted in it (Typescript window). Facts in the START world are displayed in the Output window with simple mouse interaction.

Figure C- 12: Begin by World Creation and Facts



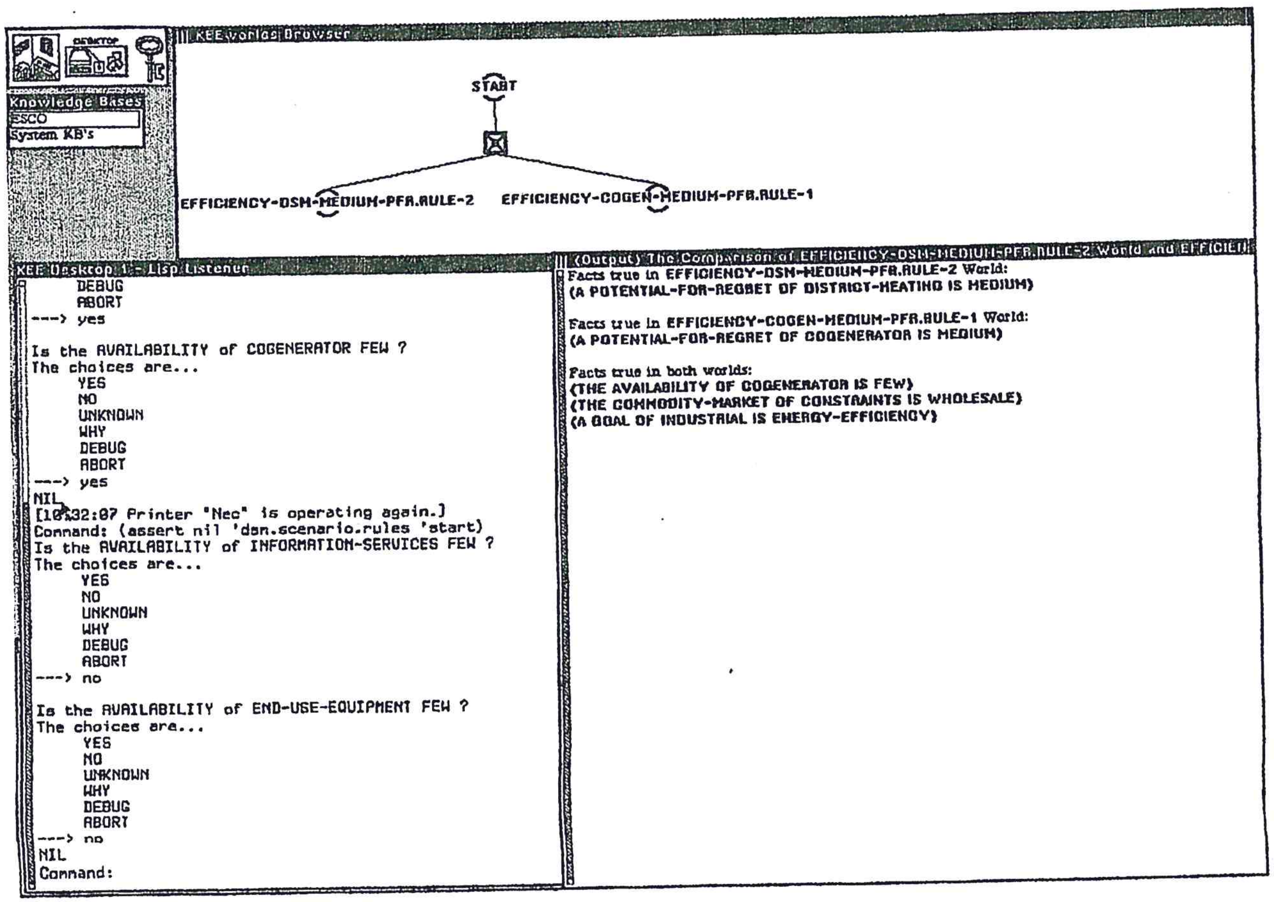
The data indicate that cogeneration may work. The scenario is created with cogen.scenario.rules. The rules evaluate antecedents and assert new facts, e.g., POTENTIAL-FOR-REGRET slot of COGENERATOR in newly created world (see Output).

Figure C- 13: Creating New Scenarios and Facts



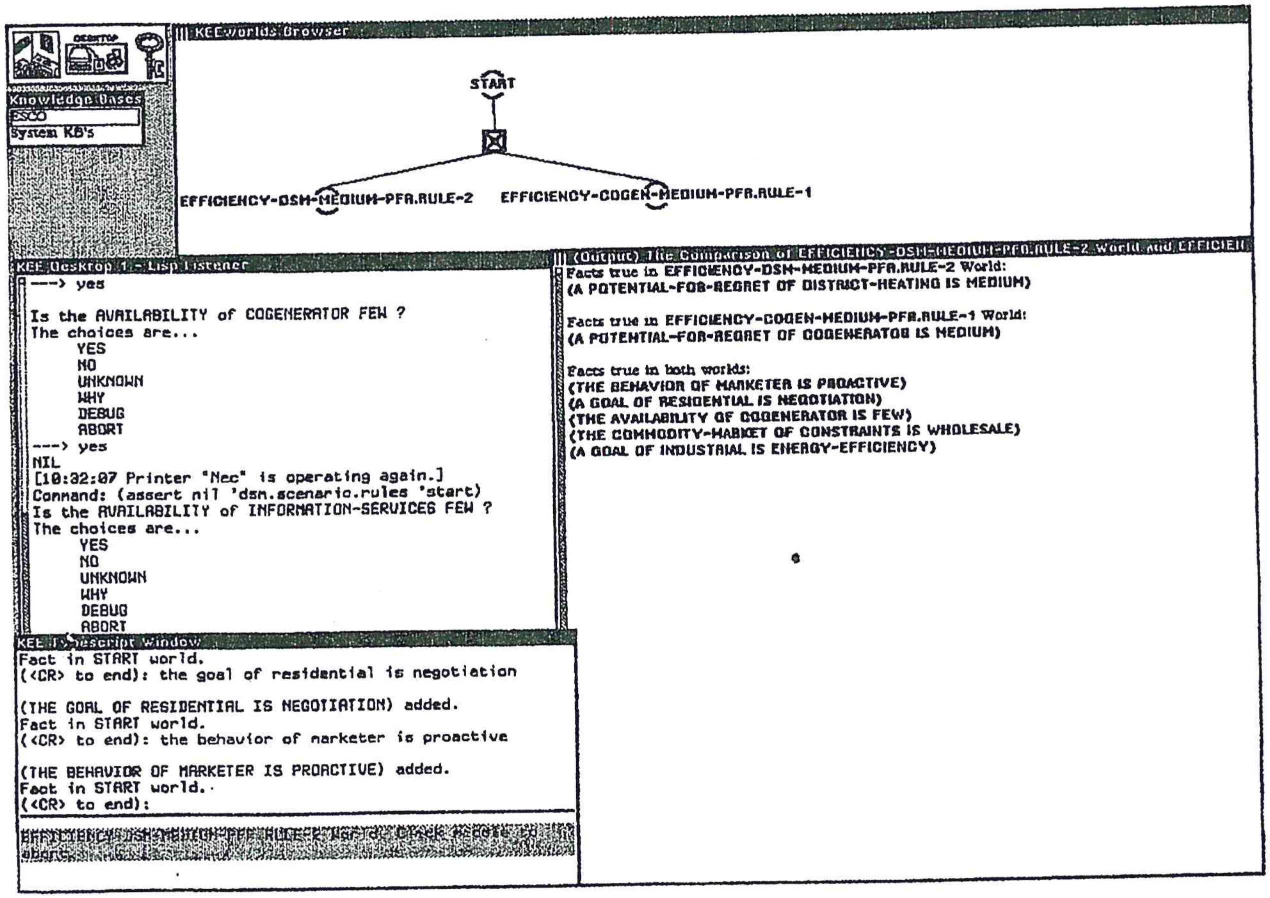
Other scenarios, e.g. district heating below, can also be created using rules. The resulting worlds and the facts within them can be compared (see Output). Note that some facts are specific to a world even if derived from the same data as other worlds.

Figure C- 14: Comparing Alternate Scenarios



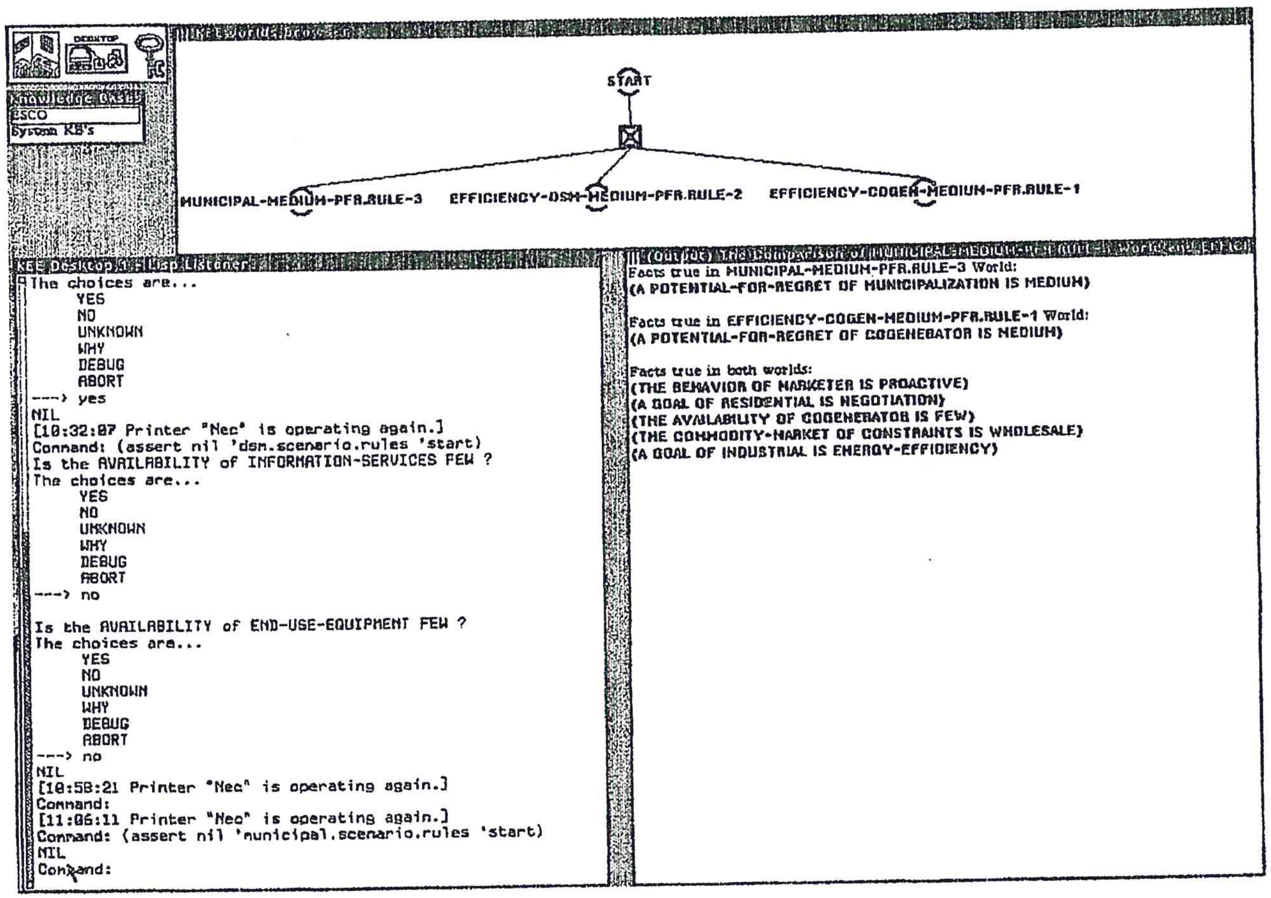
Additional facts can be asserted into specific worlds and facts are inherited automatically from parent worlds. Facts asserted into the START world below are inherited in its child worlds (see Output).

Figure C- 15: Asserting and Inheriting Facts into Worlds



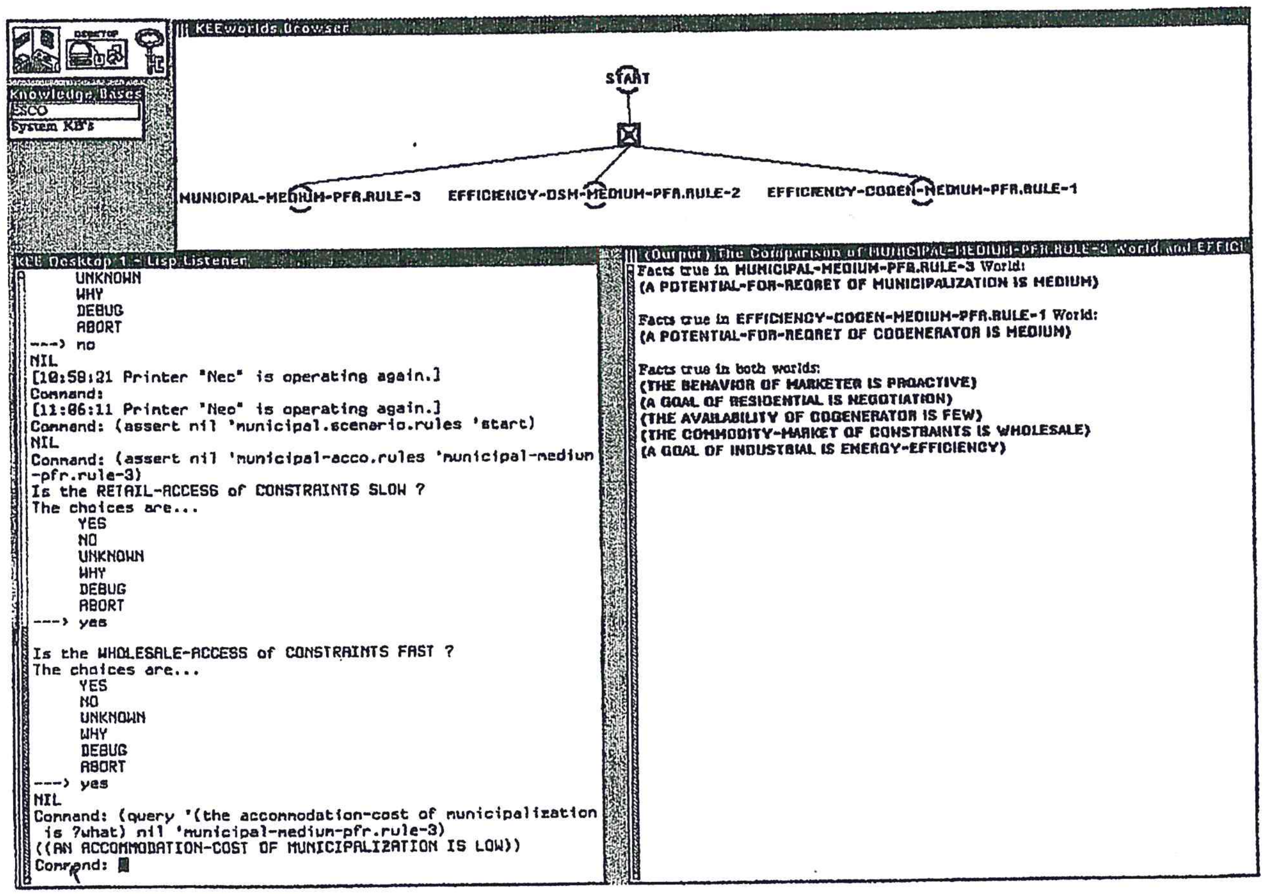
New scenarios can be evaluated at the appropriate time and from the relevant context (world). In this case, in addition to district heating and cogeneration, the user asks ESCO to consider municipalization using MUNICIPAL.SCENARIO.RULES.

Figure C- 16: Evaluating New Scenarios



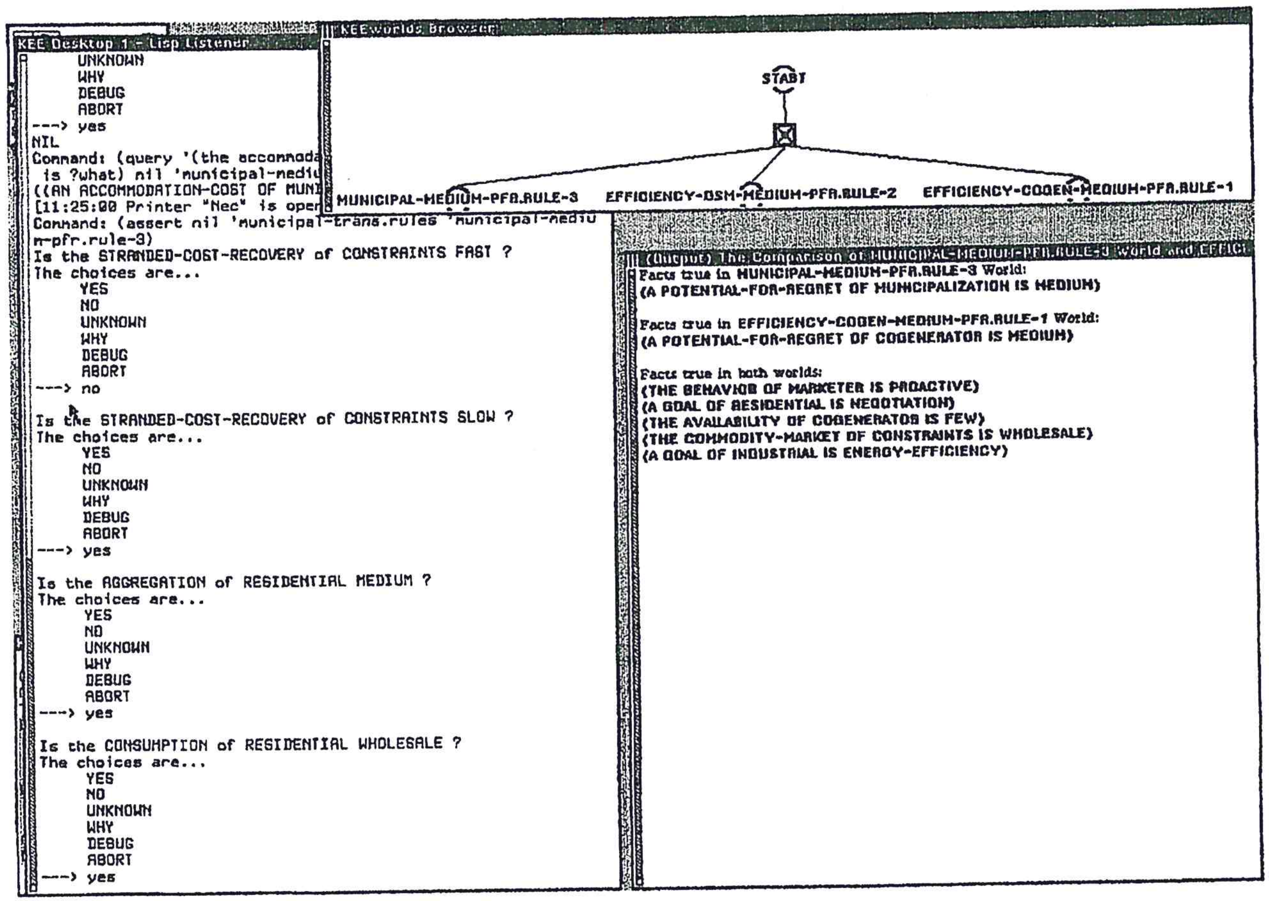
Context specific rules, such as MUNICIPAL-ACCO.RULES, enable ESCO to gather and assert (forward chain) appropriate information. Facts not directly asserted, but which can be derived (backward chain) using rules are obtained by QUERY.

Figure C- 17: Asserting Information and Deriving Conclusions



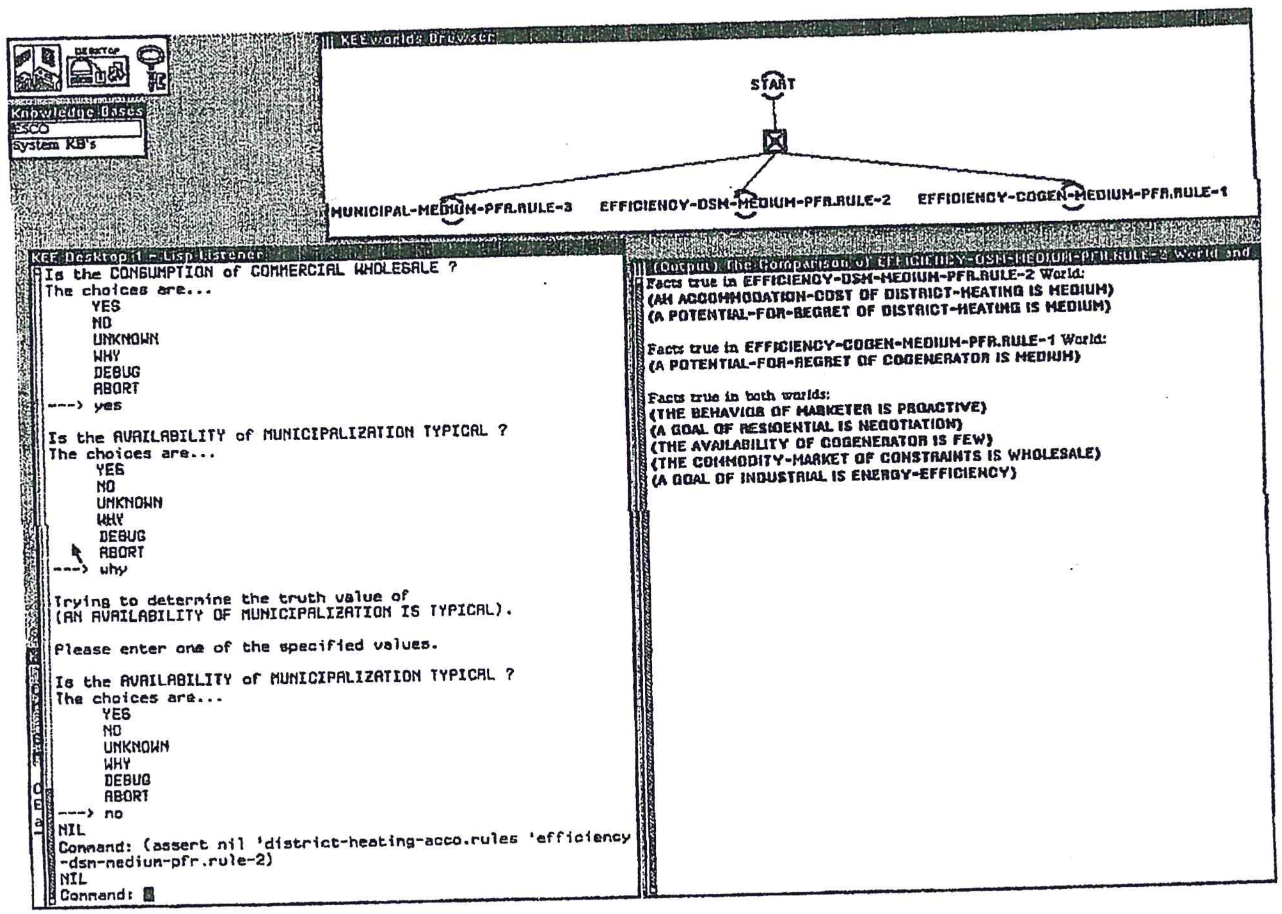
When the rules are incomplete or the information required to fire the rules is not available, the knowledge base simply rests (as against conventional programs which have to be specifically programmed to not crash).

Figure C- 18: Incomplete Information and Rules



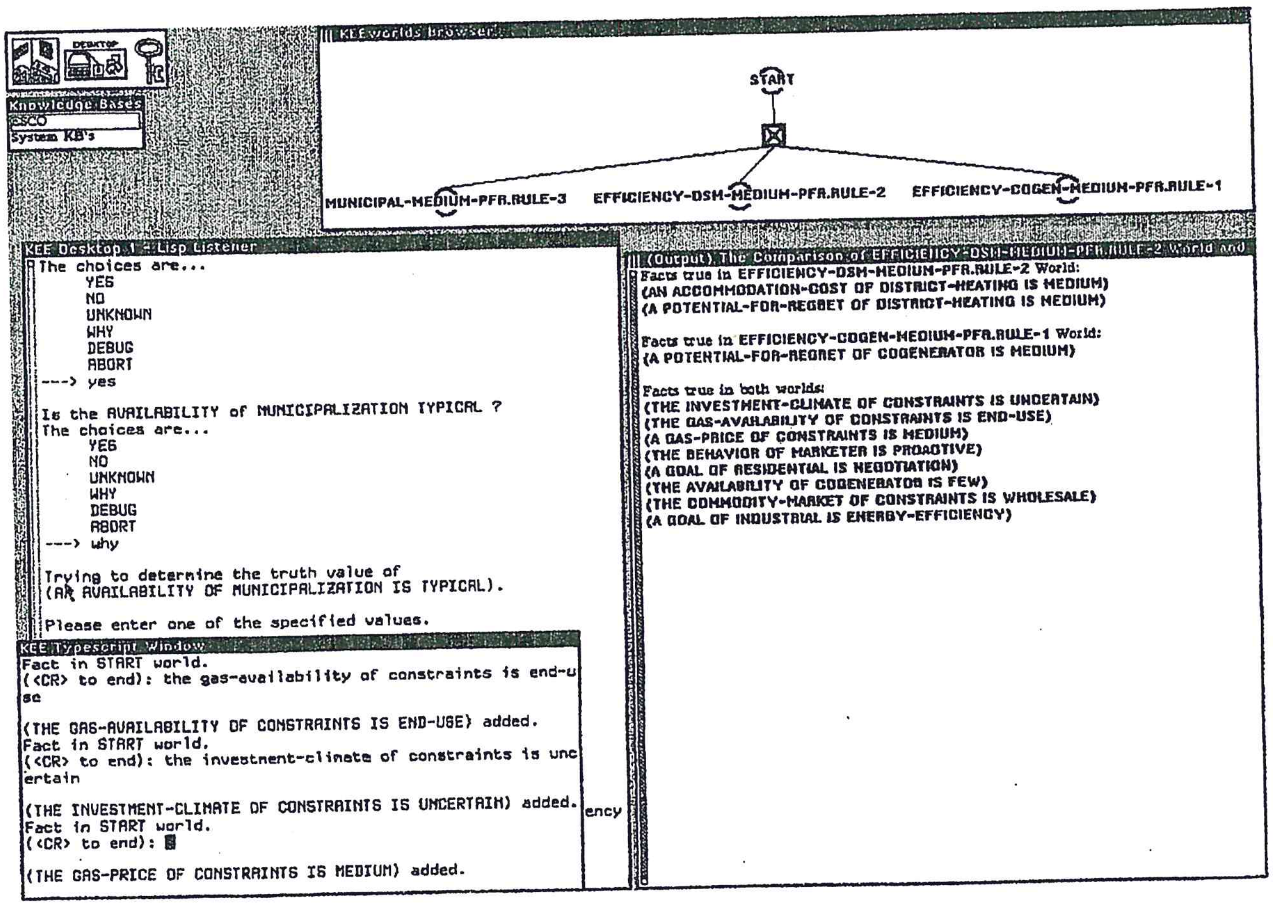
When rules are applied, derived facts are updated in the appropriate worlds in the KB, as in the value of ACCOMMODATION-COST district heating case below. In contrast to this demo, rules are typically chained automatically by class.

Figure C- 19: Facts from Successful Rules Automatically Updated



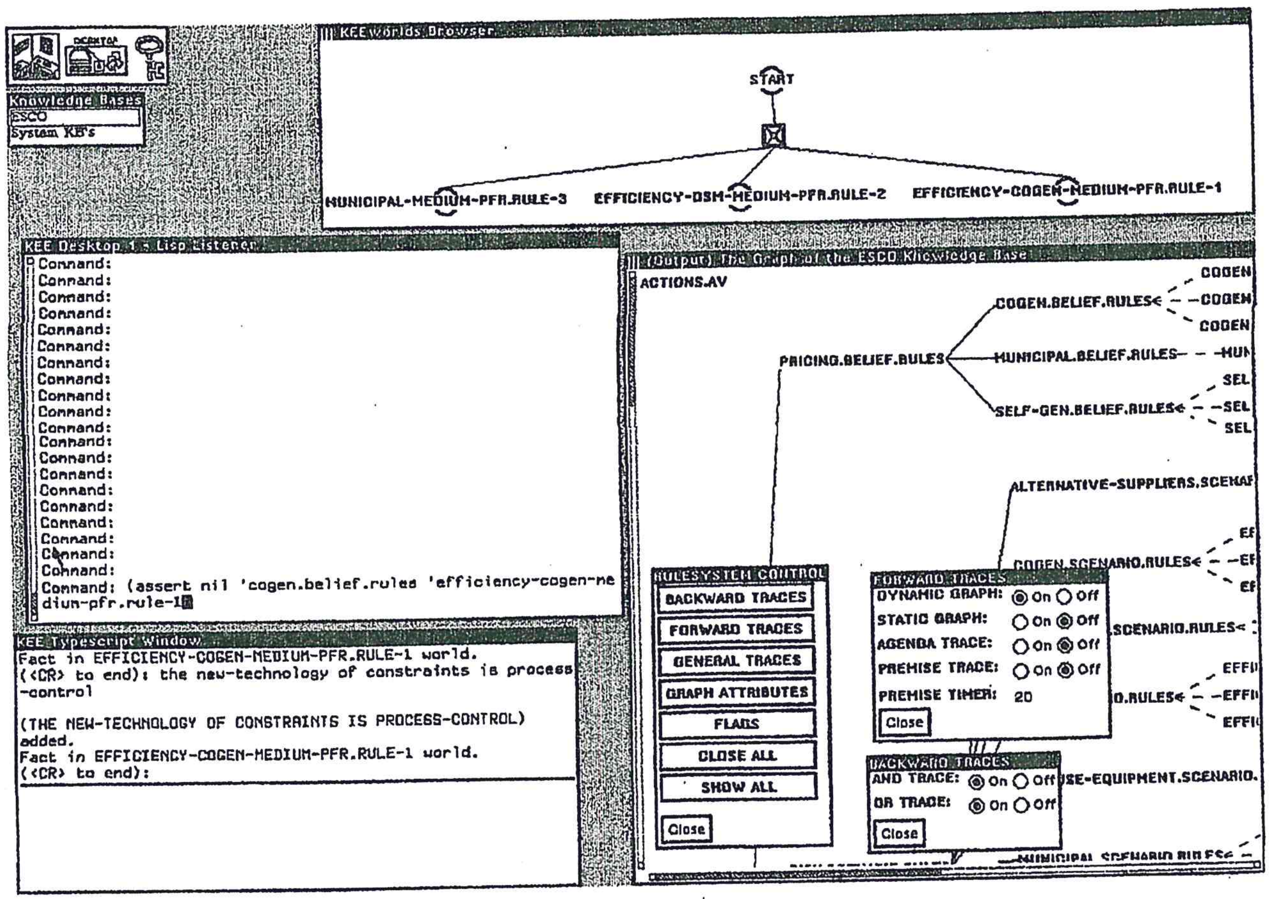
Most functions can be performed programmatically or interactively with the mouse. In the case below, the facts are asserted in START simply by clicking on the world icon and choosing the ADD FACTS item from the menu.

Figure C- 20: Adding Facts Interactively



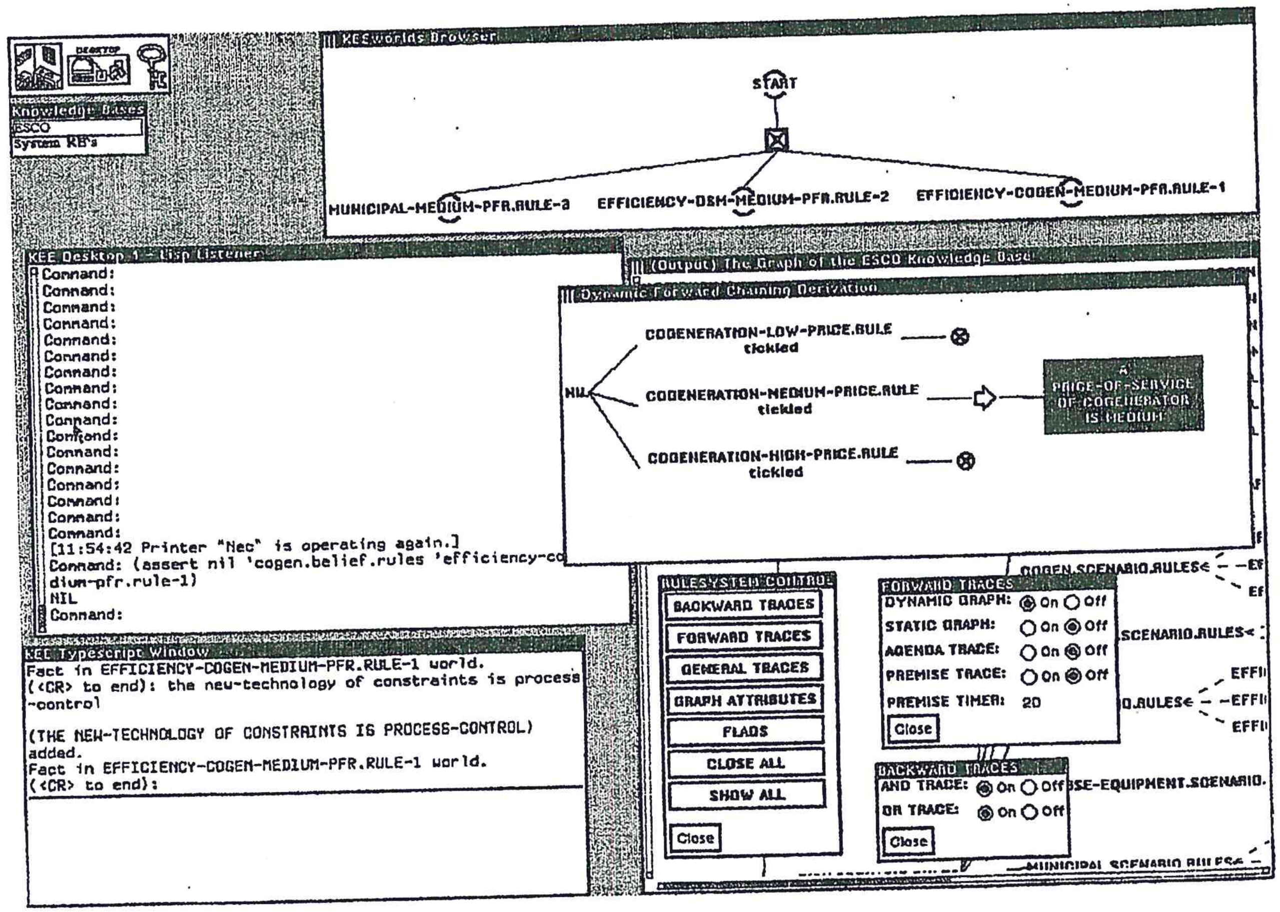
The decision process - especially followed by the ATMS belief rules - can be traced by turning on the appropriate flags in the user control. The dynamic graph (forward chaining) and the AND-OR traces (backward chaining) are switched on below.

Figure C- 21: Forward and Backward Rule Traces



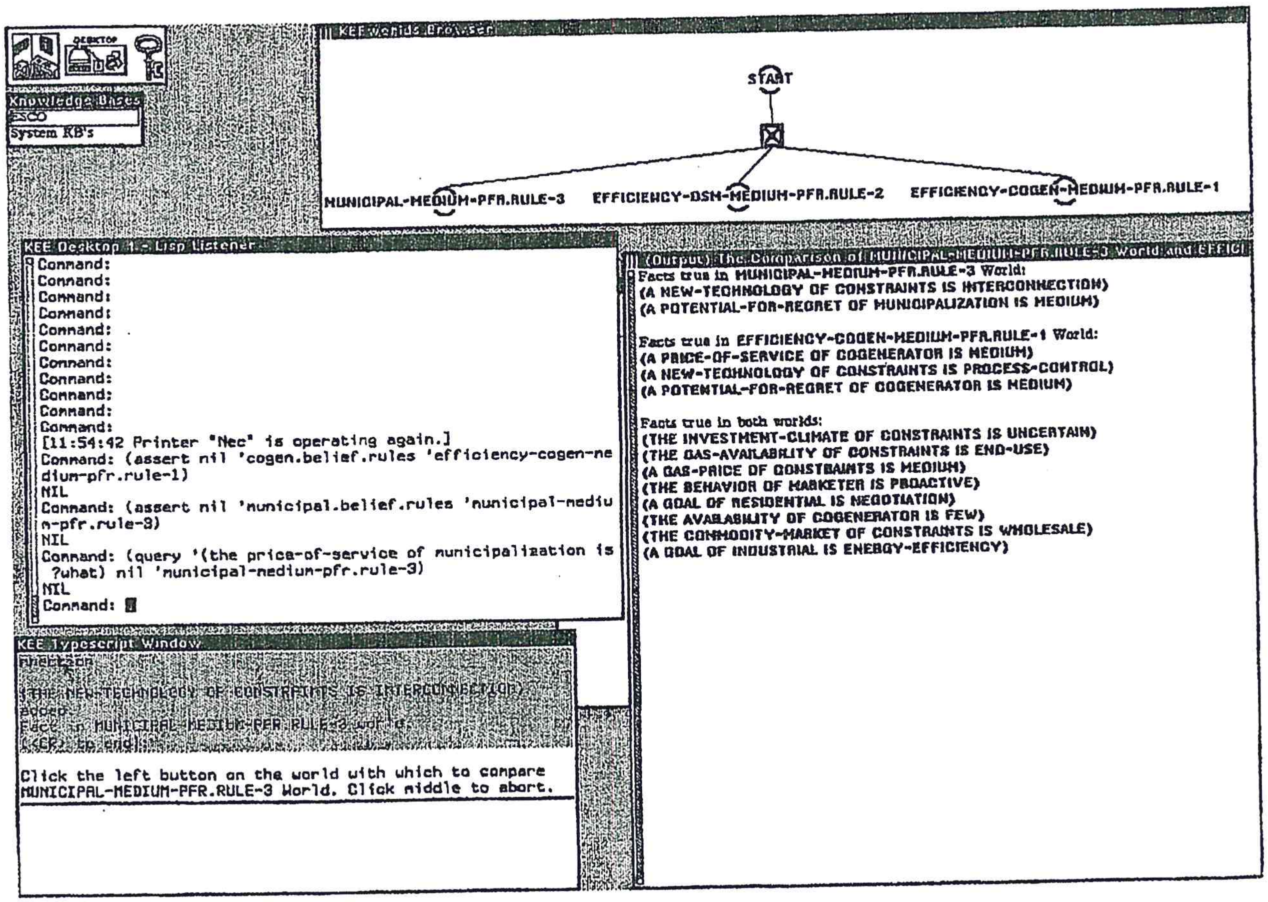
With the traces on, derivation graphs of the decision process shows which rules are tried and actually fired. The conclusions reached are also highlighted (see the DYNAMIC FORWARD CHAINING DERIVATION window).

Figure C- 22: Tracing Rules and Facts



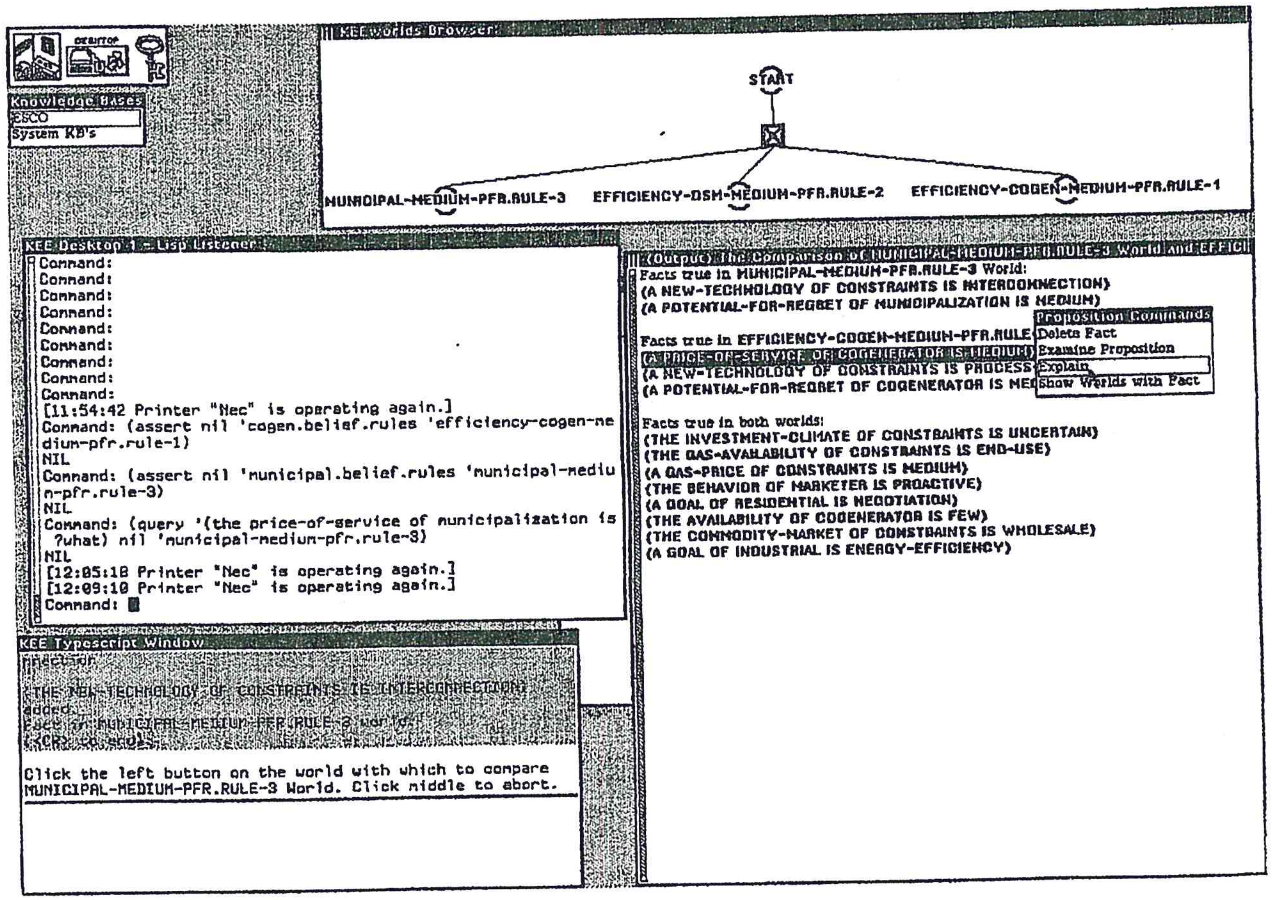
Some facts are specific to a world and not available to other worlds. Assertion of ATMS rules (MUNICIPAL.BELIEF.RULES) and a query Lisp Listener window below shows that THE PRICE-OF-SERVICE OF MUNICIPALIZATION cannot be derived.

Figure C- 23: Some Facts are not Derivable in all Worlds



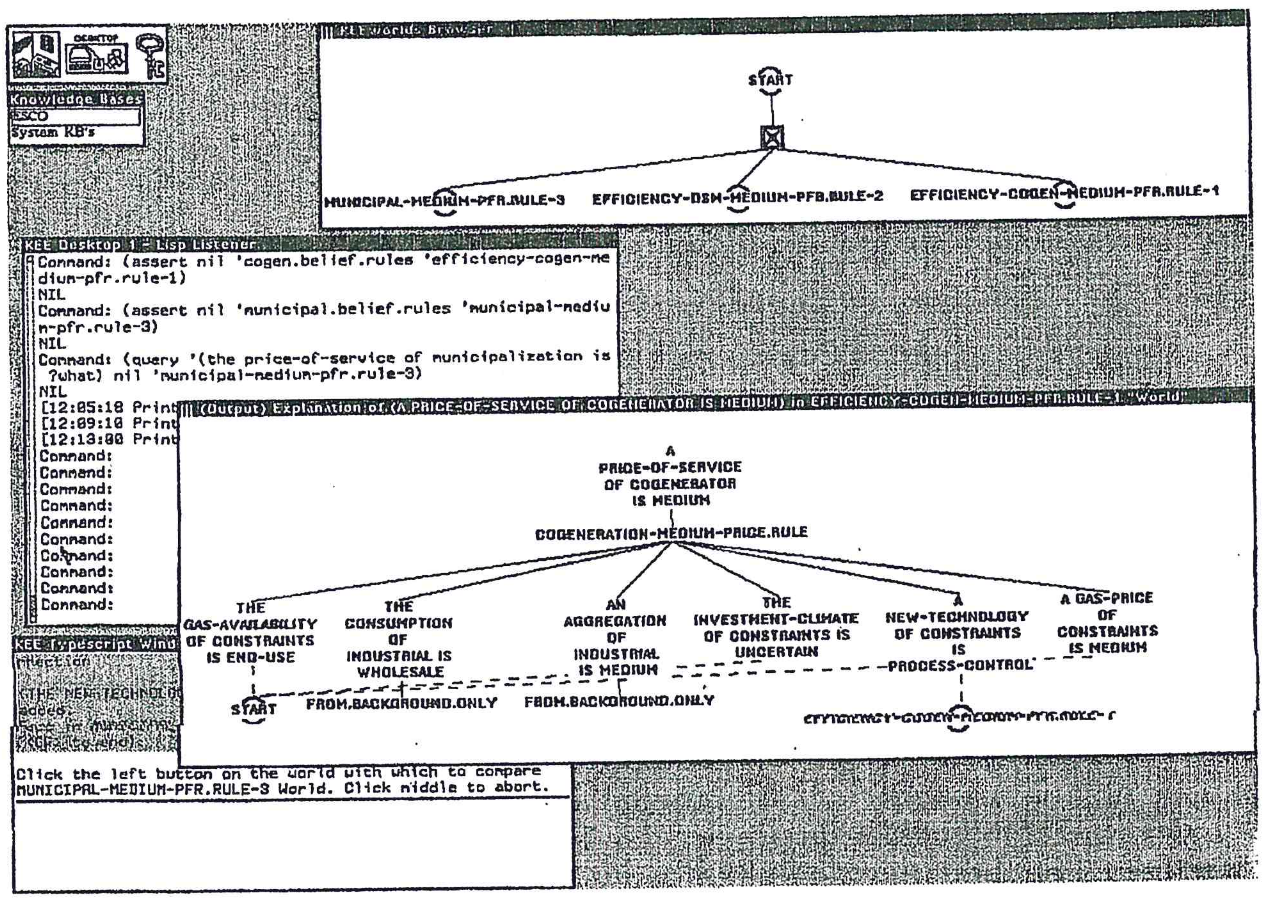
Facts can be highlighted and the supporting propositions can provide an explanation of how the facts are asserted into specific worlds. For example, an explanation is sought of the fact THE PRICE-OF-SERVICE OF COGENERATOR IS MEDIUM.

Figure C- 24: Obtaining Explanations



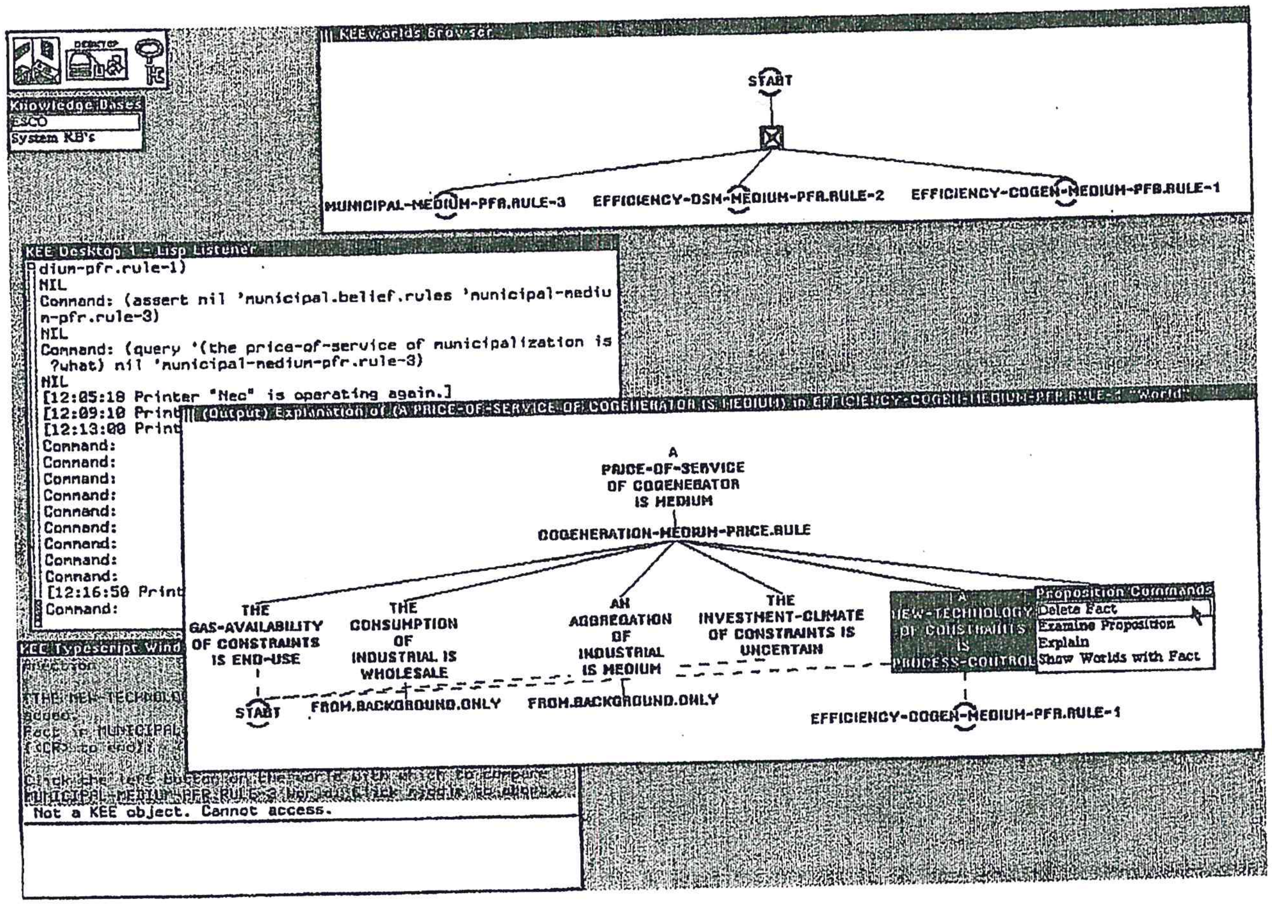
The explanation graph (in Output) shows the facts and rules used in different worlds to derive the highlighted fact is presented as a graph. Facts asserted in the BACKGROUND are available to all worlds.

Figure C- 25: Explanation Graph



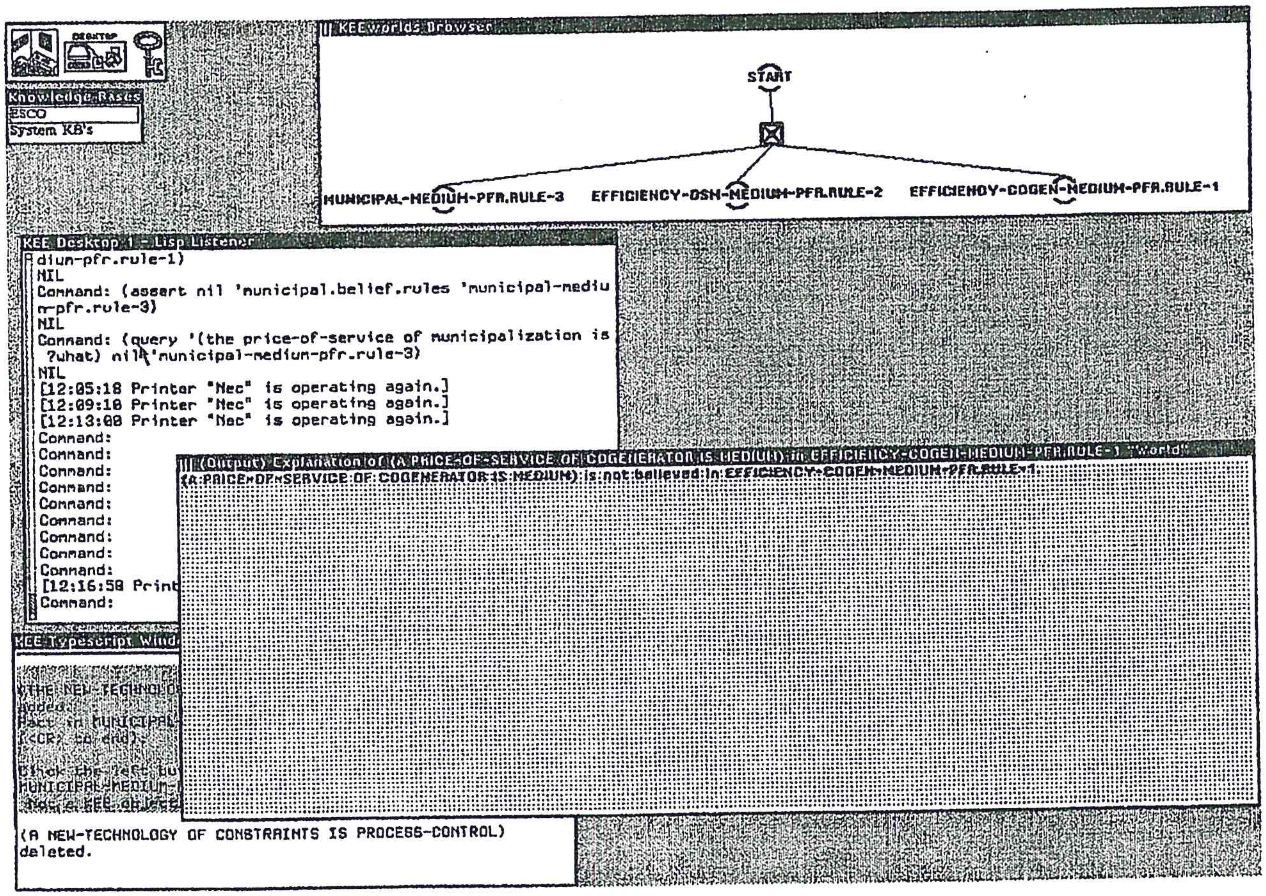
Facts on the explanation graph also can be highlighted. In the figure below a fact in the cogeneration scenario world is being deleted. The retraction of the fact (A NEW-TECHNOLOGY OF CONSTRAINTS IS PROCESS-CONTROL) will invalidate the conclusion.

Figure C- 26: Retracting a Fact



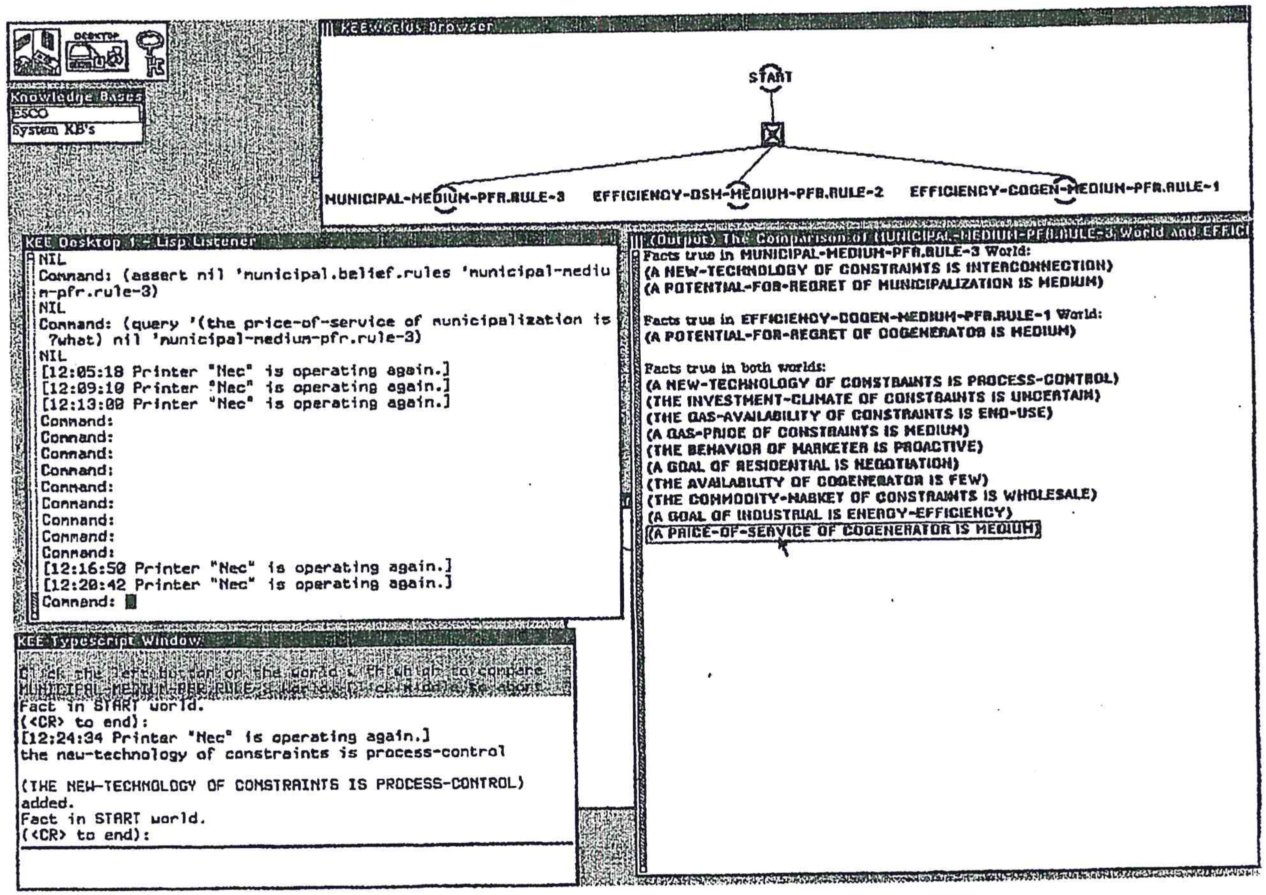
A retracted fact does not only invalidate itself and its conclusions. It retains the ATMS rule (COGENERATION-MEDIUM-PRICE.RULE) used to derive it. That is, the retracted fact is not believed but the justification structure is in place as a belief.

Figure C- 27: Retracted Fact



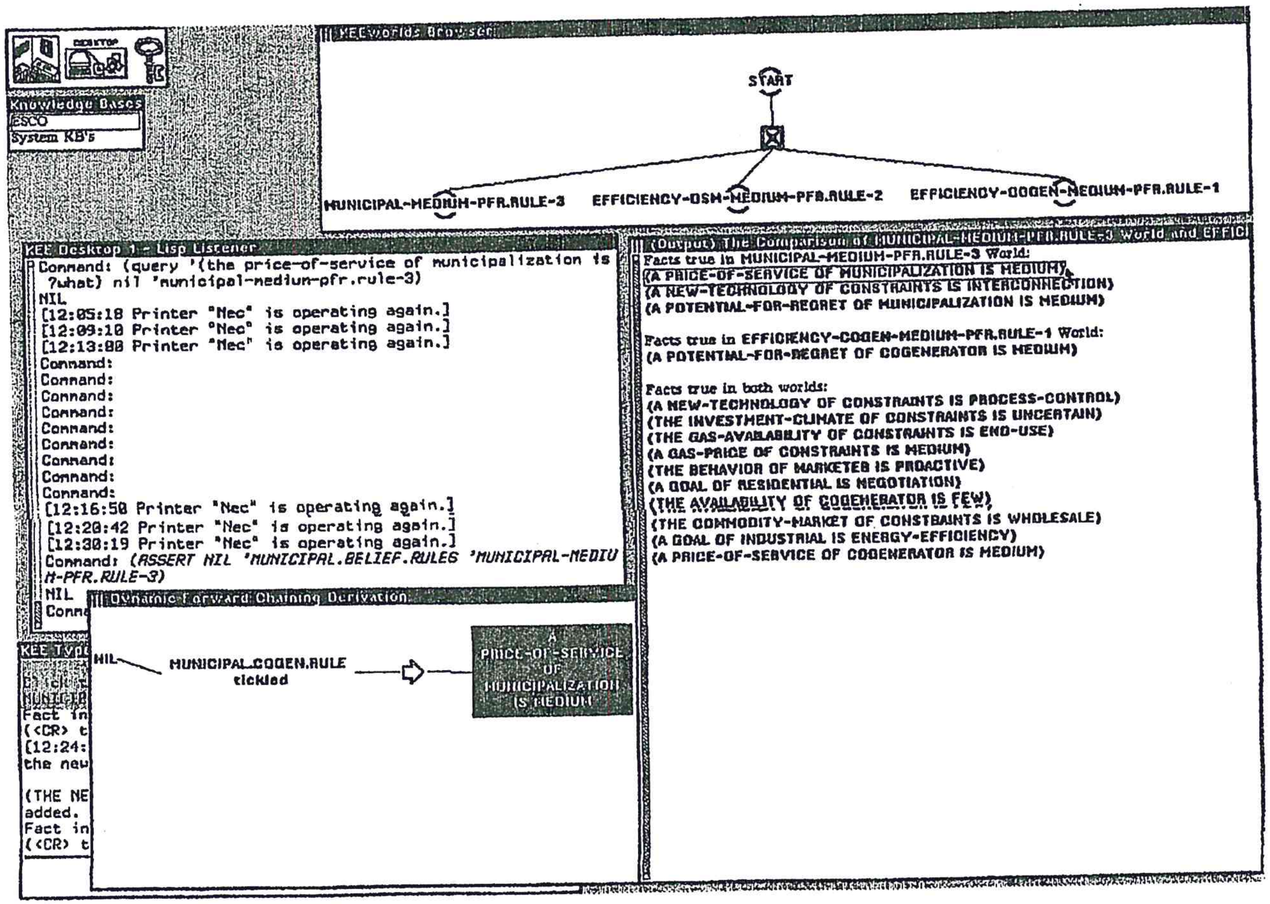
On asserting the fact (THE NEW-TECHNOLOGY OF CONSTRAINTS IS PROCESS-CONTROL) in the START world, THE PRICE-OF-SERVICE OF COGENERATION IS MEDIUM is derived in *both* worlds, i.e., cogeneration and municipalization worlds, automatically.

Figure C- 28: Automatic Derivation by ATMS Rule Justifications



In fact, now the previously failed MUNICIPAL.BELIEF.RULES can be applied to OBTAIN THE PRICE-OF-SERVICE OF MUNICIPALIZATION. Normally, such rule application is chained and non-monotonic retractions are managed automatically.

Figure C- 29: Chained Effect of Re-assertion of Non-monotonic Beliefs



Of course, an explanation graph of the recently derived fact can be obtained interactively as shown below. Keeping track of beliefs, facts, worlds, rules, and their sequence of application enables the ATMS to manage non-monotonic behaviors.

Figure C- 30: Explanation Graph Showing Chained Derivation