Project Summary

Increasingly, our understanding on workings and price outputs of commodity markets is driven by research in the areas of social networks and the ways in which market participants, otherwise known as dealers or traders, interact based on formal and informal trading processes. Much of the existing research is built around agent-based modeling and simulation, in which agents (traders) "buy" or "sell" the commodity in question over time, prices are established, and trends and other time-series phenomena are compared with real data.

This proposal is prepared to enhance the development of the existing agent-based models of electric power trading. This research is critical in understanding and modeling the ways that experienced power traders make decisions in the complex market environment and will be applicable to models of traders in other commodity markers, such as currency markets. The proposed models of short-term and long-term decision-making in a complex decision environment characterized by uncountable factors (e.g., supply and transmission constraints, weather and traders' speculation) will be based on both existing theory and interviews with real wholesale power traders.

This proposed synthesis of well-established theory from the financial economics, experimental psychology, and behavioral finance literatures, and feedback received from power traders in the context of the existing model provides the intellectual merit of the proposal. Broader impacts will be large and may be categorized in two general ways:

1. The proposed model will add to the growing literature concerned with market microstructure (in general) and will contribute to the understanding regarding how power traders actually make short-term trading decisions in dynamic auction markets.
2. The proposed model will enhance existing, well-established commodity-market modeling efforts at New Mexico Institute of Mining and Technology in both power and currency trading, and the fully-developed simulation model will be available to the public.
3. Policies regarding regulation and pricing of electric power may be assessed.

The proposed research will be carried out over an 18-month period by the Principal Investigator, the Co-Investigator, and two graduate students at the New Mexico Institute of Mining and Technology. Primary steps include: 1) an ongoing literature review, 2) interviews with power traders, 3) model development, 4) programming and simulation, 5) data analysis, 6) summary of results and 7) publication in top journals.

The proposed research will greatly enhance existing knowledge regarding the intersection of theory and practice with regard to decision-making in a complex, short-term environment, and is built upon extensive existing commodity-market modeling expertise at the New Mexico Institute of Mining and Technology.

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Complete both columns only if the proposal is numbered consecutively.

OVERVIEW

A synthesis of existing and current research in financial economics, behavioral decision theory, and experimental economics with a cutting edge wholesale power-trading simulation in the context of an enhanced model of trader behavior in a complex, information rich environment is proposed. The context is a wholesale power-trading market, in which traders are faced with the need to make bidding decisions in the face of private information about generation capacity, and public information about prices, transmission-line utilization, and weather. The current models of trader decision making, described in some detail below, will be augmented with a formal learning component that will, as noted above, be based on theory and will also be grounded in interviews with actual wholesale power traders.

The intellectual merit of the proposed research is grounded in the connection between actual trader behaviors and inputs to the modeling process, existing and emerging academic literature, and the existing, innovative wholesale power-trading model developed at New Mexico Institute of Mining and Technology. A key output of the proposed study will be a model of trader bidding behavior that incorporates learning in the context of short-term expected utility maximization in a complex informational environment. We know of no such model of wholesale power-trader behavior.

Successful completion of the project will have broader impacts in several key areas. First, the existing power-market model at New Mexico Institute of Mining and Technology will be greatly enhanced, and the model will be made publicly available via the Internet. This dissemination of the model will greatly enhance coursework in modeling in simulation (an emerging teaching area for upper-division undergraduate and graduate students) at New Mexico Institute of Mining and Technology and other schools around the United States and the world. Second, a contribution will be made to existing academic research in several key areas. Third, the model will provide public agencies with the means to analyze and assess proposed public policies toward generation, transmission, and pricing of electricity.

The next section of the proposal contains a discussion of the overall problem of modeling agent learning in the context of the wholesale power-trading model. This is followed by a technical discussion of the research effort undertaken by the Principal Investigator in this area and a summary of existing power-trading software and simulation models. The third section contains a timeline and a brief summary of key activities during the proposed 18-month duration of the project. This is followed by sections concerned with methodology and anticipated results; which conclude the proposal.

PROJECT DESCRIPTION

I. PROBLEM STATEMENT

An agent-based approach, discussed in this proposal, has been applied to investigate various complex systems such as a wholesale power trading auction. The applicability of the agent-based approach can be found in not only computer science but also decision science and operations research. For example, Samuelson [1] has discussed how the agent-based approach can be applied to various social science systems from the perspective of optimization. Similarly, Makowski *et al.* [2] have assembled seventeen articles, all of which discuss a linkage between the agent-based approach and various complex systems.

An important feature of the agent-based approach is that it incorporates the structure of a complex system in its modeling process. The validity of an agent model is numerically expressed and examined by a simulation-based investigation. Hence, the approach is known as a computer-intensive method. The incorporation of the problem structure, along with the simulation study, provides us with an opportunity to understand the behavior of a complex system where many components have complicated interactions among them. Historically, analytical approaches, based upon optimization, are applied to handle the complex system. However, these approaches often face a difficulty in dealing with the complex system, because the complex system is usually expressed by a very large nonlinear and/or integer programming model. Consequently, it is very difficult for us to solve the large complexity problem, especially if the system in question is dynamic as well as complex. Meanwhile, the agent-based approach is gradually recognized as a promising approach among researchers in natural and social sciences, because it can effectively deal with various types of complex systems.

Admitting that the agent-based approach has a high research potential, Principal and Co-Investigators (PI and CI) find that the approach has a major difficulty in real applications. That is, a complex system is numerically structured by many unknown parameters. A behavior of the complex system is examined in a simulation where the unknown parameters are initialized as random numbers. Unfortunately, the simulation does not provide any implication (rationale) regarding what is the best (or better) combination of parameters in predicting the behavior of the complex system. Thus, the practicality of the approach has never been established in previous research.

To deal with the difficulty, Sueyoshi and Tadiparthi [3] have incorporated adaptive learning capabilities into an agent-based approach which is designed to investigate a dynamic behavior of power trading. This new approach, equipped with learning capabilities, can determine unknown parameters through an adaptive process. A contribution of their study is that they have documented the importance of an agent-based approach that is combined with machine learning (originated from artificial intelligence in computer science). Their research effort opens up a new intelligence system for complex analysis. Hereafter, this proposal refers to their agent-based approach as

"Agent-based Intelligent System (AIS)" in order to distinguish itself with other agent-based approaches that are usually not equipped with learning capabilities.

To enhance the practicality and theory regarding the new intelligent system, the proposed study needs to mention that there are still two major drawbacks on AIS. One of the two is that the previous research does not discuss how to document the practicality of AIS. The other is that the previous research does not sufficiently establish a linkage between AIS and literatures in experimental economics, behavioral decision theory, and financial economics, as well as the experimental psychology literature on both human and animal learning. Experimental psychology has long served as a theoretical basis for developing various adaptive models.

Practicality: To document the practicality of AIS, the proposed research will compare the performance of AIS with other well-known methods (e.g., neural network and genetic algorithm in computer science as well as time series and forecasting methods in statistics), using real data and artificially generated data. The methodological comparison examines whether AIS performs as well as other well-known approaches in predicting a dynamics of a complex system.

Theoretical Extensions: This proposed study will develop several adaptive models for AIS. One of the several groups implies a group of agents whose adaptive behaviors work with a high level of rationality. The high rationality can be identified in their bidding decisions that use risk-averse utility functions. Moreover, the agents are equipped with advanced machine learning capabilities. Meanwhile, the other group of agents is equipped with myopic learning. They do not include any utility function. Limited machine learning capabilities are incorporated into their adaptive behaviors. Thus, agents in the second group make their bidding decisions with a low level of rationality. The proposed research generates many different types of adaptive agents between the two groups.

When exploring the theoretical extension, the proposed investigation attempts to establish a theoretical link among expected utility-maximization, myopic decision making models of AIS and experimental psychology within the literature on behavioral decision theory. This proposed links may be attained by the following research efforts: (a) First, the proposed research will refine the current theoretical learning model of a power-market bidding behavior by a risk-averse, short-term trader in a dynamic trading environment. This will be done by incorporating a dynamic model of bidding behavior that is contingent upon time, the behavior of other traders and physical conditions as described and forecasted by weather reports. The information that a power trader must use for bidding in the power market must be aggregated quickly. Hence, the proposed investigation proposes a simple model for this process with parameters that are updated based on the factors mentioned above. Development of this model in an expected-utility framework will provide a theoretical contribution with practical-application potential in a variety of other contexts in which individuals quickly make valuation decisions that are based on a variety of dynamic factors, such as currency-exchange market models. (b) Second, the proposed research will connect the myopic trader model with well-established anchoring and adjusting models from experimental

psychology and behavioral decision theory. This model will also be developed in a dynamic context, where the anchor and subsequent adjustment will be also a function of information about other dealers' behavior and physical/weather conditions.

Complex System (wholesale power trading): The complex system investigated by the proposed research is wholesale power trading where many controllable and uncontrollable factors are related each other in a complicated manner. The complexity of power trading is due to unique features of electricity that are different from other commodities. First, electricity cannot be stored as found in other commodities. Second, a constant monitoring system is required to stabilize a balance between supply and demand; both are often expressed by a non-linear relationship. Third, most residential consumers are, on a short time, unaware of or indifferent to a price change. In other words, price elasticity is considerably small, compared with other commodities. Finally, demand is influenced by a change in temperature and a seasonal change. A large amount of demand occurs in summer and winter, depending upon a place where the demand occurs. In addition to the unique features of electricity, a price change in a wholesale power market occurs due to other socio-economic and engineering factors. Such factors include (1) an imperfect market structure, (2) a possible existence of a market power, (3) a line limit on transmission and an occurrence of congestion, (4) different speculation views among traders, (5) imperfect information on transmission, (6) different bidding approaches among traders, (7) a system failure and a maintenance problem, and (8) a price change of fuel (e.g., coal, oil and natural gas). Thus, the wholesale power market is considered as a complex system in the proposed research.

II. PREVIOUS RESEARCH EFFORTS

A. Previous Research Efforts of PI

Previous research efforts of the PI (Toshiyuki Sueyoshi), which are closely related to the proposed research, include the following articles:

(1) "A Wholesale Power Trading Simulator with Learning Capabilities," IEEE Transactions on Power Systems (2005) Vol. 20, No. 3, pp.1330-1340.

(2) "An Agent-based Approach to Handle Business Complexity in US Wholesale Power Trading" IEEE Transactions on Power Systems (Forthcoming in 2007).

(3) "Wholesale Power Price Dynamics under Line Limits in Transmission: A Use of Agent-based Intelligent Simulator" IEEE Transactions on Power Systems (Under Review).

The first article discussed such a new use of AIS which was applied to a wholesale trading auction of electricity. In the article, the US auction market is separated into DA (Day Ahead) and RT (Real Time) whose market structure is very similar to PJM (Pennsylvania – New Jersey – Maryland) which is the largest ISO (Independent System Operator) and RTO (Regional Transmission Organization) in the United States. The research has proposed an intelligent simulator in which learning capability of traders accumulate their bidding experience and make a new bidding strategy to increase their winning probabilities. Using the software, the study has investigated both how traders determine a market clearing price in DA and RT and how the price change occurs under different trading environments.

The second article extends the third article. In the article, the performance of AIS is compared with other well known approaches such as neural network and genetic algorithm. The comparison confirms that the proposed AIS perform as well as the other well-known methods in price estimation. In the study, two adaptive models are prepared for the proposed AIS. One of the two consists of adaptive agents who are equipped with advanced learning capabilities and exponential utility functions. The other group consists of adaptive agents who are equipped with myopic learning capabilities. A simulation study confirms that the myopic learning model outperform traders with the advanced learning model in estimating a market price fluctuation. The finding is consistent with a reality on power trading: traders must make their bidding decisions within a limited time. Their decision making processes are characterized by bounded rationality and limited information processing capabilities, even though they look for optimality of a net gain from their trading. The simulation result does not imply that advanced learning models do not serve as a theoretical basis of the agent-based approach. The other simulation confirms that the advanced learning model outperforms the myopic learning model in an artificial market in terms of a total reward. It is concluded in the forth article that a theoretical investigation on advanced learning is as important as myopic learning.

The last article discusses how to incorporate a line limit on a transmission line system in AIS. So, it becomes an extended version of AIS. The simulator developed in the research can numerically examine how a capacity limit on an interconnection line influences a dynamics of a wholesale power market. Thus, the extended version of AIS is designed to incorporate various pricing strategies for power trading, considering both a line limit on an interconnection line and an occurrence of congestion. Furthermore, the wholesale power market is structured by multiple zones in the extended version. Different market prices are identified for different zones that consist of a wholesale market of electricity. The original studies consider only a single market. In this sense, the previous research implications are limited from a practical perspective. However, the extended version of AIS overcomes such difficulties due to both a line limit on transmission and multiple market zones in a power market so that it can numerically investigate how the line limit influences the price and volatility of wholesale electricity. Based upon our best knowledge, the article is the first research effort that includes the transmission issue in the agent-based approach.

B. Existing Software for Power Trading

Existing market software for power trading, available as open-source, are as follows:

PowerWeb: This software was developed at Cornell University and was designed to operate various power markets by interacting with human decision makers on a web-based tool. The generators are each modeled by a human trader. This model considers single uniform auctions in DA market with a constant demand. This software does not have flexibility to model the behavior

of a trader in simulation. This software ignores RT and long term markets.

Agentbuilder: This software was developed for a market protocol that uses software agents to buy/sell electricity. It uses concepts of decision theory and uses three strategies for buying and selling. All these strategies are represented by smooth curves (monotonically increasing/ decreasing) representing the bidding behavior of an agent. The drawback of this model is that the agents cannot adapt or change their bidding behaviors during simulation. This model ignores the presence of a system operator and implements only Dutch auction.

SEPIA (Simulator for Electrical Power Industry Agents): This software was developed at University of Minnesota. It uses adaptive agents and object oriented modeling techniques. These adaptive agents use discovery informatics to develop and identify patterns that help in understanding an environment. This model uses evolutionary learning techniques like incremental genetic algorithms. Even though agents are equipped with learning, the market is not modeled to handle complex scenarios like congestion. Furthermore, this software does not consider auction markets like DA and RT. It only considers the long-term market.

MASCEM (Multi Agent Simulation System for Competitive Electricity Markets): This software is a market simulator that makes use of Open Agent Architecture (OAA) to create a rule-based system. Since it uses existing agent architecture, it is easy to extend and develop this model. The agent's bidding strategies are represented by monotonically increasing/decreasing functions. This design does not implement the transmission system.

EMCAS (Electricity Market Complex Adaptive System): This software was developed at Argonne National Labs., uses a complex adaptive system approach to represent agent learning and adaptation. It tests regulatory structures using genetic algorithm. The agent's objectives are characterized by a utility function. The main shortcoming of this tool is that it does not provide a predictive capability to understand a time trend of a power market.

All the existing software models described above ignore a transmission market or a line limit in a transmission network. Table 1 summarizes a comparison of all the software models described above. Each model was evaluated from the perspective of four dimensions: Prediction, Decision-making, Analysis, and Intelligence. It was observed that none of the existing software attempt to predict the market price.

Table 1: Comparison between Existing Software and Our Software (AIS)

	Prediction	Decision Making	Analysis	Intelligence
PowerWeb	No	Yes	Yes	No
Agentbuilder	No	Yes	No	No
SEPIA	No	No	Yes	Yes
MASCEM	No	No	Yes	Yes
EMCAS	No	Yes	Yes	Yes
AIS	Yes	Yes	Yes	Yes

Note: AIS stands for Agent-based Intelligence System.

III. Research Activities and Time Schedule

The proposed research can be separated into seven research activities:

(1) The PI will conduct a literature survey on agent-based approach and power trading in the library of the Ohio State University from September to December in 2006.

(2) Both PI and CI will conduct an interview study (many site visits) which provides PI and CI with an opportunity to examine how real traders make their bidding decisions in a wholesale power market. The survey will be done from January to March in 2007.

(3) Both PI and CI will develop a model that numerically expresses the bidding strategies of power traders within a framework outlined above. The model development will be done from March to June in 2007 within New Mexico Tech.

(4) Under the supervision of PI, two research assistants will develop the power trader network simulation program within New Mexico Tech. The programming activity is the most time consuming part of this study that needs 6 months (from June to December in 2007). The programming uses C# (a programming language) to connect multiple computers that solve effectively the proposed power trading model.

(5) Under the supervision of PI, the two research assistants will conduct a simulation study that investigates a price fluctuation of wholesale electricity. The simulation study will be conducted within New Mexico Tech from January to March in 2008.

(6) The PI and CI will work on data analysis that compares the performance of the proposed approach with other well-known methods. The data analysis will be done within New Mexico Tech from March to June in 2008.

(7) Finally, the PI and CI will prepare two articles that summarize simulation results.

Thus, it is envisioned that the project needs two annual periods for completion. These research activities and time schedules are visually summarized in Table 2.

Table 2: Time Schedule for Research Activities

		06/9	07/1	07/3	07/6	07/9	08/1	08/3	08/6	08/9
1	Literature Survey	=====> Literature Survey (06/9 - 06/12)								
2	Interview Study on Auction Trade		========> Interview Study (07/1 - 07/3)							
3	Modeling on traders (AI Formulation)			========> Modeling (07/3 - 07/6)						
4	Network Programming				===========> Network Programming (07/6 - 07/12)					
5	Simulation						Simulation (08/1 - 08/3) ========>			
6	Statistical Analysis							Statistical Analysis (08/3 - 08/6) ========>		
7	Preparing Research papers								Research Papers (08/6 - 08/9) ============>	

IV. Methodology

A. Numerical Representation (Modeling) of Power Trading

In AIS, a wholesale power market is structured by DA and RT markets, as mentioned previously. In each market generators and wholesalers consist of agents (traders) whose bidding strategies are examined by AIS. Each trader independently behaves for the enhancement of its own interest or benefit. Based upon the previous bidding results (success and failure), each trader accumulates knowledge for its future decision-making. The bidding processes of traders in both DA and RT can be visually summarized below in Figure 1.

Assumption: n generators ($i = 1, .., n$) and k wholesalers ($j = 1, .., k$) participate in the DA and RT markets at the t-th period ($t = 1, .., T$).

Supply Side Strategy in DA Market: s_{it}^{m} is the maximum power generation capacity of the i-th generator at the t-th period. The generator bids s_{it}^{1} as the amount of power generation for DA ($s_{it}^{1} \le s_{it}^{m}$). Here, the superscript "1" indicates the DA market and the subscript "t" indicates a power delivery time. The bidding amount s_{it}^{1} is expressed by $\alpha_{it} s_{it}^{m}$, where α_{it} $(0 \le \alpha_{it} \le 1)$ is a parameter to express the ratio of the bidding amount to the maximum capacity.

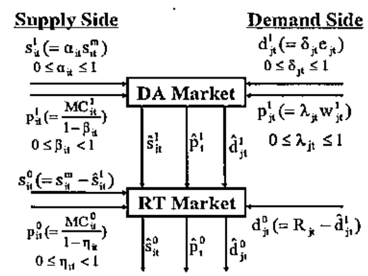

Figure 1: Bidding Structure for Wholesale Market

Let MC_{it} be the marginal cost of the i-th generator at the t-th period. Each generator determines a bidding price (p_{it}^{1}) for the DA market by $p_{it}^{1} = MC_{it}/(1-\beta_{it})$. Here, β_{it} $(0 \le \beta_{it} < 1)$ is a mark-up rate of the generator for the DA market. The mark-up rate expresses numerically how much the bidding price is inflated from the marginal cost. The mark-up rate reflects a price strategy toward the DA trading. Considering different magnitudes of β_{it}, the simulator examines various price strategies in the DA market. After s_{it}^{1} and p_{it}^{1} are submitted by all generators into ISO, the organization determines the real allocation ($\hat{s}_{it}^{1}$) for each generator in the DA market. The real allocation is determined by the DA market and it is different from s_{it}^{1} (a bidding amount).

Supply Side Strategy in RT Market: In the wholesale market, each generator is expected to allocate the whole generation capacity to the DA and/or RT market. Hence, the i-th generator bids

$s_{it}^{0} = s_{it}^{m} - \hat{s}_{it}^{1}$ in the RT market, where the superscript "0" indicates the RT market. The pricing strategy of the generator is expressed by $p_{it}^{0} = MC_{it}/(1-\eta_{it})$, where η_{it} is a mark-up rate $(0 \le \eta_{it} < 1)$ and p_{it}^{0} is the bidding price of the generator. In the RT market, ISO obtains their bids on s_{it}^{0} and p_{it}^{0} from all generators to determine $\hat{s}_{it}^{0}$ (a real allocation for the generator) and $\hat{p}_{t}^{0}$ (a market price) through the RT market.

Demand Side Strategy in DA Market: Let e_{jt} be the demand estimated by the j-th wholesaler or ISO. The wholesaler predicts a bidding price (w_{jt}^{1}) by using a function (IF) of demand. That is, $w_{jt}^{1} = F(e_{jt})$. In AIS, the wholesaler makes a demand bid (d_{jt}^{1}) whose amount is less than or equal to e_{jt}. That is, $d_{jt}^{1} = \delta_{jt} e_{jt}$, where δ_{jt} $(0 \le \delta_{jt} \le 1)$ is a parameter to express how each bid is strategically reduced from the demand estimate. Similarly, the bidding price for demand is determined by $p_{jt}^{1} = \lambda_{jt} w_{jt}^{1}$. Here, $\lambda_{jt} (0 \le \lambda_{jt} \le 1)$ is a parameter for price adjustment from the estimated price. Both d_{jt}^{1} and p_{jt}^{1} are submitted to the ISO and then the organization determines $\hat{d}_{jt}^{1}$ (a real power allocation to the wholesaler) and $\hat{p}_{t}^{1}$ (a market price) in the DA market.

Demand Side Strategy in RT Market: In the RT market, all the wholesalers specify their required quantities on electricity. It is assumed that they must purchase all the necessary electricity from DA and/or RT markets. Let R_{jt} be a real demand for the j-th wholesaler on the delivery day. The wholesaler specifies the purchasing amount, $d_{jt}^{0} (= R_{jt} - \hat{d}_{jt}^{1})$, in the RT market. The ISO adjusts all the requests from market participants to determine $\hat{d}_{jt}^{0}$ (a real allocation) and $\hat{p}_{t}^{0}$ (a market price) through the RT market.

Function of ISO in DA and RT Markets: In the DA market, n generators bid their s_{it}^{1} and p_{it}^{1}. Similarly, k wholesalers bid their d_{jt}^{1} and p_{jt}^{1} in the DA market. In the proposed simulator, ISO reorders their biddings of generators and wholesalers. That is, the supply side combinations (s_{it}^{1} and p_{it}^{1}) are reordered according to the ascending order of these bidding prices (p_{it}^{1}). Meanwhile, the demand side combinations (d_{jt}^{1} and p_{jt}^{1}) are reordered according to the descending order of these bidding prices (p_{jt}^{1}).

B. Machine Learning

As depicted in Figure 1, the power trading is numerically expressed and therefore, it can be solved by AIS. A computational issue is still remained here, because many unknown parameters are associated with the power trading scheme depicted in Figure 1. It is indeed true that all the unknown parameters are expressed between zero and one as a result of such a numerical expression. However, none knows what the best or better combination of parameters is.

Conventional agent-based approaches usually generate random numbers for identifying these parameters that consists of a market price for DA and RT on market equilibrium. The convergence issue becomes an important computational issue. Meanwhile, the previous studies on AIS prepared by PI did not follow the conventional approaches, rather directing toward a new AI-based

approach that includes machine learning capabilities into the agent-based approach. This type of research has been not investigated in the conventional studies on agent-based approach.

Some important features of the adaptive learning process incorporated in AIS are explained as follows:

Adaptive Learning: In AIS, traders accumulate knowledge from their bidding results to adjust their bidding strategies. The adaptive learning process is separated into (1) a knowledge accumulation process and (2) an own-bidding process. The knowledge accumulation process provides each trader with a win-loss experience as a result of their biddings. After the learning process is over, traders start their own bidding decisions based upon their previous trading experiences. Of course, they update and accumulate their knowledge at each trading. Figure 2 visually specifies such an adaptive learning process.

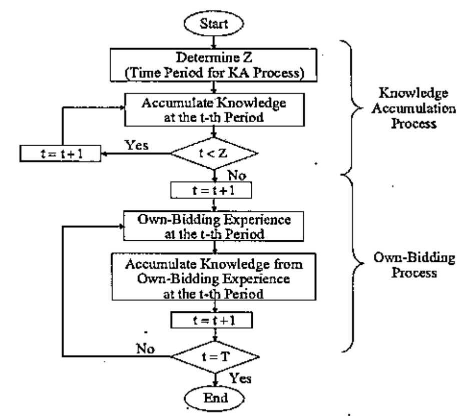

Figure 2: Adaptive Learning Process

Adaptive Decision Rule: The win or loss of a trader is considered as a binary response. The win/loss status of the i-th generation is predicted by the following linear probability model:

$$r_{it} = c_{i0} + c_{i1}\alpha_{it} + c_{i2}\beta_{it} + c_{i3}\eta_{it} + \varepsilon_{t}.$$

Here, r_{it} is a reward given to the i-th generator at the t-th period. Parameters are denoted by c_{i0}, c_{i1}, c_{i2} and c_{i3}. An observational error is listed as ε_{t}. Those parameters are unknown and, hence, need to be estimated by OLS (Ordinary Least Squares) regression. The winning probability (Prob) of the j-th generator at the t-th period can be specified by

$$\mathrm{Prob}(W_t) = \mathrm{Prob}(r_{it} \ge 0) = \mathrm{Prob}\{\varepsilon_t \ge -(\hat{c}_{i0} + \hat{c}_{i1}\alpha_{it} + \hat{c}_{i2}\beta_{it} + \hat{c}_{i3}\eta_{it})\}$$
$$= \frac{e^{(\hat{c}_{i0} + \hat{c}_{i1}\alpha_{it} + \hat{c}_{i2}\beta_{it} + \hat{c}_{i3}\eta_{it})}}{1 + e^{(\hat{c}_{i0} + \hat{c}_{i1}\alpha_{it} + \hat{c}_{i2}\beta_{it} + \hat{c}_{i3}\eta_{it})}}$$

The symbol (^) indicates a parameter estimate obtained by OLS. The above equations suggest that the winning probability can be determined immediately from parameter estimates of the sigmoid model. The above formulations for a generator can be applied to a wholesaler, as well, after replacing these unknown decision variables by ones (δ_{jt} and λ_{jt}) related to the wholesaler.

Based upon the estimated wining probability, all traders make their bidding decisions on price and quantity of electricity. However, the probability is a guess of each trader. The market price (as a final result) is determined by a market mechanism. Hence, a high wining probability does not imply that a trader can win in a market.

Exponential Utility Function: It is assumed that all the traders have an exponential utility function. The utility function represents a risk aversion preference on a smooth concave function. Mathematically, the exponential utility function is expressed by $U(R_t) = 1 - EXP(-\zeta R_t)$ on $R_t \geq 0$, where R_t is a reward for each trader and ζ indicates a parameter to express the level of risk aversion. Thus, we can determine the magnitude of a bidding change (τ) along with a previously determined strategic direction. Different utility values produce different magnitudes of τ. Different values on the magnitude suggest different bidding prices and amounts for each trader.

This is one component of the existing model that will be extended in the proposed research. Risk-averse traders will differentially weight information from a variety of sources (weather reports, system capabilities, private and public information concerning the activities of other traders) as a function of the risk attitude of their organizations and other externally-imposed constraints.

V. EXPECTED RESULTS

Expected results obtained from the proposed research can be classified by three perspectives: (1) research, (2) pedagogy and (3) social contribution.

Research: Based upon the proposed research, both PI and CI will prepare two manuscripts and submit them for publication in academic journals such as *Artificial Intelligence* and *Management Science*. The proposed research will incorporate many different types of adaptive learning models in AIS, and will compare them with simulation results obtained when traders are modeled using the results of this proposed study. As is widely known, previous research efforts on AI (Artificial Intelligence) applications are directed toward gaming and robotics. Many different types of adaptive learning models are developed for gaming and robotics. The proposed research will utilize such previous adaptive learning models in AIS. We use the adaptive models to explore various learning processes of power traders. In this research, the previous adaptive learning models need to be modified in a manner that these models can be used from gaming/robotics to power trading. The results are not obtained in the previous research and are summarized for publication of the AI journal.

Furthermore, using our AIS, both PI and CI are interested in reexamination of two policy issues. One of the two is that we will investigate why the price hike occurred in California. The

AIS will develop an artificial market that duplicates the power crises in California and re-examine why the problem occurred in our simulation. The proposed study will provide several policy implications on the design of US power market. Such policy implications will be documented and submitted to publication of *Management Science*.

Pedagogical Development: A benefit of the proposed research is availability of software for AIS. The software provides graduate students with virtual trading experience which may generate scientific interest in a computer application to business and public policy. The classes (EMGT 501: Management Science for Engineering Management, EMGT 572: Social System Modeling and Simulation, and MGT 472: Production Analysis and Operations Management) within New Mexico Institute of Mining and Technology (also New Mexico Tech) will incorporate the software as part of these pedagogical materials. Furthermore, Ohio State University (USA), Shizuoka University (Japan), Warwick University (England), University of Otaga (New Zealand) and National Cheng Kung University (Taiwan) will use the software in their business classes. Of curse, the software will be put on the website of PI so that any university in the United States can utilize the software for these pedagogical purposes.

Social Contribution: Many policy makers, corporate executives and individuals, who are involved in the power industry, are looking for a policy guidance regarding how to determine an appropriate wholesale price of electricity. The software provides us with an opportunity to obtain information and policy implications on the price setting scheme of electricity in AIS-based simulation For example; it is widely known that the current policy direction of US deregulation expects a reduced electricity price. The policy desire may be attained by opening many wholesale markets in the United States. However, the reduced wholesale price does not reduce a retail price of electricity when congestion occurs on a transmission line. The wholesale price for electricity is usually determined by supply and demand in a power exchange market. An occurrence of congestion increases a wholesale price because a capacity limit on an interconnection line restricts power supply from other zones. It is believed that there is no perfect policy. There exist always a winner and a loser in any policy implementation. Returning to this proposal, the winner is an owner of a transmission line who obtains a large profit from an occurrence of congestion and the loser is a consumer. Using the proposed AIS simulator, we can investigate a future electricity policy on how to allocate a profit due to congestion in order to build a new transmission system. That is an important policy application of the proposed research.

Long-Run Goal: Finally, it is important to note that both PI and CI are looking for the development of a new research area. It is hoped that the proposed research provides us with an important one step for such a new research area. Thus, the proposed research is important in pursing the long-run goal of both PI and CI.

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