Energy Price Prediction using Fuzzy Techniques

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Abstract **- Fuzzy information was an issue of interest for scientists since the 1920s. The introduction of the fuzzy theory in 1965 by Lotfi A. Zadeh enabled a novel view on uncertain information. Stochastic modeling is an important tool for researchers and decision makers. In this paper we investigate the application of fuzzy information into prediction models. The introduction of uncertainty into statistical models provides a good opportunity to gain realistic prediction results. We present two prediction techniques using fuzzy logic in stochastic modeling, named the artificial neural network and the fuzzy rough set system.**

I. INTRODUCTION

The introduction of fuzzy logic fifty years ago enabled the development of numerous intelligent information systems, which captured nearly every field of life. The very first considerations on fuzzy logic go back to Platon who stated, that there must be a third area between the terms “right” and “wrong” [1].

Already at the end of the Middle Ages, in the 15th century, Nikolaus von Kues (Cusanus) emphasized, that all quantitative measurements underlie a fundamental inevitable inaccuracy. During the following 400 years natural sciences developed towards being more and more descriptive and analytic, exhibiting an increasing fundamental need of measurements. Sciences were driven forward by developing mathematical and statistical methods with a focus on constructing machines to make diverse natural phenomena measureable, such as time or temperature. Always having in mind to simultaneously reduce this unavoidable amount of fuzziness during measuring procedures. About eighty years ago the term “information” became an important scientific issue, initially being connected only with the transmission of messages. Rapidly it became a fundamental scientific term, similar to *energy* and *matter*. The originator of cybernetics, Norbert Wiener, emphasized that information owes a quality unlike and unrelated to matter and energy [2].

Since the 1920s the investigation of uncertain or fuzzy information became an interesting issue for scientists, e.g. initial A. Tarski or J. Łukasiewicz, who investigated multi-valued logics [3], [1]. The computational starting point with uncertain contents was then set by the Iranian-American engineer and computer scientist Lotfi A. Zadeh, when he introduced the fuzzy theory in 1965 at the University of California in Berkeley. Basically, fuzzy logic is described by the existence of fuzzy sets. A fuzzy set consists of objects with a gradual quality of being in membership with a certain category or class. The belonging to a specified class remains imprecisely defined, e.g. “*all real numbers that are much bigger than 1*” [4]. The fuzzy theory can be seen as generalization of the Boolean logic, in which originally the truth values of variables could be 0 or 1. In contrast, fuzzy logic allows the truth values of variables to be any real number *between* 0 and 1.

The application of real numbers into models is in many cases questionable. Thus, the introduction of fuzzy numbers into statistical models provides a good opportunity to implement realistic models. However, fuzziness is not meant to replace probability theory in these cases. A hybrid approach showing the combination of both kinds of uncertainty lead to a more realistic description of data in modeling procedures [2].

In this manuscript two applications of fuzzy logic in prediction techniques are characterized which are the fuzzy rough set system and an artificial neural network implementing fuzzy technique.

II. FUZZY NUMBERS AND FUZZY SETS

Profound decision making processes depend on appropriate quantitative description of investigated items, which are measurements, observations, but also a priori information from experts. There is a huge amount of real information which cannot be described by exact numbers and vectors in an adequate manner. First of all this is true for linguistic statements, e.g. the term “elevated temperature”, which does not indicate an upper or lower limit and thus remains an imprecise expression. Another example was mentioned by Lotfi A. Zadeh, 1965, stating “*all real numbers that are much bigger than 1*”. It remains questionable, if the designation of an exact upper and lower limit is useful and should be determined. As an alternative to the description of exact numbers and sets the implementation of fuzzy sets became an important subject. There are several reasons that determine the existence of fuzzy data. At one hand it might overall not be possible to define exact data in any way. On the other hand different data sources may provide different items so that only an upper and lower limit can be defined, but not a single precise number. A further reason can be the given fundamentally occurring imprecision of measuring tools, e.g. due to rounding on digital displays or, even more visible, on analog readouts, e.g. reasoned by vibrating needles. A fourth reason may arise when an objective scale of values is absent, such as the value of realities or valuable articles. In those cases, when the investigated quantities cannot be described by precise real numbers but only by the upper or lower limit, the data is characterized by an interval number, which is defined as a special case of fuzzy numbers.

It must be emphasized that, of course, not all data is imprecise, uncertain or fuzzy. Discrete values such as the results of counted items, or account balance are represented by exact numbers [2].

Briefly, discrete refers to countable and continuous refers to uncountable quantities.

III. Fuzzy Data and Stochastics

The term stochastics is derived from the ancient Greek and means “*someone, who is skillful in supposing*” [2]. In many applications the concrete values of particular observations are uncertain. The uncertainties in the description of continuous quantities were considered as stochastic quantities when introduced in modeling. Uncertainties of continuous quantities were thus expected to be only stochastic and are thus characterized by random variables. However, the fuzziness of data described above is quite distinct from stochastic uncertainty and cannot be evaluated by stochastic modeling. It must be pointed out that this non-stochastic fuzziness of data refers to the fuzziness of a single observation and can be introduced into modeling by the application of fuzzy numbers and fuzzy vectors. The theory of fuzzy numbers and fuzzy vectors enables the description of non-stochastic uncertainty. Thus, the generation of realistic models is enabled by the combination of both stochastic and fuzzy uncertainty [2].

A. *Mathematical Basics*

The exact sciences essentially depend on quantitative descriptions of observed phenomena and quantities, usually performed by numbers. In many cases exact numbers are note adequate for the description of measurement results, due to its imprecise measurement characteristics. The idea to describe fuzzy data and fuzziness respectively, was originated from Karl Menger (1902 – 1985) and was derived from the classical set theory:

Each subset A of a set M is defined by its indicator function IA : M → {0,1}

defined as

$$\mathrm{IA}(x) = \begin{cases} 1\, f\ddot{u}r\; x \in A \\ 0\, f\ddot{u}r\; x \notin A \end{cases} \quad \forall\, x \in M \cdot$$

When a set A is determined, for each element of set M, clearly has to be defined if belonging to subset A or not. The only possible decisions are either belonging to A or not belonging to A. However, this precise decision giving a yes or no answer, indicating 0 or 1, cannot be made always. The belonging of an element to a set or subset is in many cases either not possible or useful.

In 1951, Karl Menger published his idea of a kind of fuzzy sets named ensembles flous. His idea was, not to determine the membership of every single element of a basic set M, belonging to a subset A, but to enable a stepwise or partial membership, which is referring to a generalized indicator function. Lotfi A. Zadeh named these subsets fuzzy sets in 1965 when introducing the fuzzy set theory. [2]

A fuzzy subset A* of a set M is described by the membership function μA* (•)

$$\mu A^* : M \rightarrow [0, 1] \cdot$$

The fuzzy subset A* is standardized if

$$\exists\, x \in M : \mu A^*(x) = 1 \cdot$$

According to the membership function, the membership of an element to a set can not only described by 0 or 1 but also by all values of the interval [0, 1] .

The membership degree of other x to the fuzzy subset A* is described by

$$\mu A^*(x) \text{ for } x \in M$$

Associated with this generalization and a multi-valued logic the term fuzzy logic was introduced. Fuzzy numbers allow an appropriate description of imprecise measurement results and play the central role in fuzzy logic. A fuzzy number x* is described by its characterizing function

ξ x* (•) :

A real function $\xi_{x^*}(\cdot)$ characterizes a fuzzy number x^* if

(1) $\xi_{x^*} : R \rightarrow [0, 1]$

(2) $\forall \delta \in (0, 1]$

The so-called δ-cut is defined as $C_\delta(x^*) := \{ x \in R : \xi_{x^*}(x) \geq \delta \}$

F (R) defines the set of all fuzzy numbers.

The support the fuzzy number x^* is defined as

$$supp(x^*) := \{x \in R : \xi_{x^*}(x) > 0\} \cdot$$

It has to be noticed, that the characterizing function is not completely identical with the definition of Lotfi Zadeh´s membership function. The membership function is more generalized and allows fuzzy sets being identical with their complements, which is contradictory to the assumption.

IV. Fuzzy Logic and Soft Computing

In the late 20th century there started an intelligent systems revolution which goes parallel with the information revolution and is still ongoing. According to Zadeh it can be described as an evolving higher Machine IQ (MIQ) enabling the existence of smart products, e.g. smart cameras, smart software or smart robots. He also stated, that the information and intelligent systems revolution are not only coexisting but also demonstrate a symbiosis and require each other. Referring to this fact he emphasizes the increasing importance of soft computing techniques: "*Basically, soft computing is an association of computing methodologies which includes as its principal members fuzzy logic (FL), neurocomputing (NC), evolutionary computing (EC) and probabilistic computing (PC). An essential aspect of soft computing is that its constituent methodologies are, for the most part, complementary and symbiotic…*" [5]. Soft computing can also be described as a contrast to "hard" computing or conventional computing that only allows two truth values and precise solutions. In the contrary, soft computing solutions show a tolerance of uncertainty and imprecision. [6], [7]

Today it appears nearly impossible to find any computational areas without fuzzy techniques. Since there are various real problems to deal with, which can be described by fuzzy sets but might need something more to solve the computational problem, this led to the use of heuristic algorithms inspired by nature or society when exact algorithms were not capable of presenting a solution. Reference [8] proposed another definition of soft computing as a series of methods dealing with problems in a similar way humans will do.

The tremendous importance of soft computing techniques in general and fuzzy logic especially, is in its applicability in many fields associated with computational techniques and has captured today´s private and public life. Examples can be found in most of the intelligent machines and devices in our homes and also in economics. Decision making processes are an important issue for managers both in governmental and economic institutions and depending on quantitative descriptions of investigated values and realistic information input.

Thus, raising attention is being payed to the application of fuzzy techniques in price forecasting models, indicated in publications on electricity price, stock price, crude oil price and volatility forecasting. Among all available energy resources crude oil, its products and natural gas play the most important role in economy, since they still represent slightly more than 52% of the worldwide total energy supply and consumption [9].

V. Fuzzy Set Theory in Finance Research

Human percipience and judgement of actions or events is very uncertain and subjective, depending on personality. Thus, through this involvement of inexactness it can be called fuzzy. The traditional theories in financial market analysis do not consider these circumstances. Reference [10] suggests fuzzy set theory as an applicable tool to handle these imprecisions, since it allows a gradual evaluation of the membership to a certain set. In financial research, as in many other fields, linguistic variables represent a certain degree of inexactness and uncertainty, which is why the application of fuzzy set theory in this area is supposed to be an eligible tool. Linguistic terms tend to be imprecise and uncertain and are thus regarded as fuzzy sets. The existence of fuzzy sets is also an important issue in decision-making processes which are significantly influenced by uncertain circumstances, such as psychological parameters. It is suggested, that the implementation of fuzzy techniques in financial research would be a supportive tool. In classical set theory binary terms define the membership of an element to a certain set, which can be answered as a yes/no or a 0/1 question. However, in fuzzy set theory, the 0/1 answer is extended to yes – no and all the elements in the area between [10].

A. Prediction Techniques using Fuzzy Logic

The prediction of oil prices is an important issue for investors and traders, since crude oil prices are influenced by a wide range of factors and are thus highly volatile [11]. Forecasting oil price volatility can contribute to economic stability, since highly fluctuating oil prices can cause increasing inflation and negative effects on oil-importing as well as oil-exporting countries [12].

1) Artificial Neural Network and Fuzzy Logic

Although stock market returns were stated to be predictable by past returns and various other macroeconomic factors, forecasting still remains a very challenging issue, since many variables can have an effect on stock prices [13], [14]. Reference [15] found, that recent literature supports the application of soft computing techniques such as artificial neural networks, fuzzy systems, support vector machines (SVMs) and genetic algorithms for predictions in the area of finance. Using Adaptive Network-Based Fuzzy Inference System (ANFIS) as a prediction tool, they investigated if the stock market return on the ISE (Istanbul Stock Exchange) National 100 Index can be predicted. ISE stands for Istanbul Stock Exchange. ANFIS is based on artificial neural network and fuzzy logic. The chosen data for this study were monthly released macroeconomic indicators. A MATLAB environment was used to perform the model. In this study it was shown that by the application of ANFIS stock price prediction was significantly improved. They demonstrated that the ANFIS model is an eligible tool for stock price prediction.

2) Fuzzy Rough Set System

In this study the chosen method for stock price prediction is the fuzzy rough set system, which is a hybrid approach combining rough set theory and the fuzzy linguistic approach. Predicting stock price trends requires more than human cognitive capacity. Although many traders have a deep knowledge of the market, computational support is required to handle huge amounts of available market data. Unexpectedly, the results for neural networks were not auspicious. Fuzzy rough set method, introduced by Z. Pawlak in 1991 [16], was expected to extract knowledge from databases more efficiently, which has been successfully proved by numerous scientists. For decision makers in financial markets it is of high importance to hold successful tools in their hand capable of finding rules in huge data volumes, which cannot be analyzed and interpreted manually. The rough set system of this paper consists of a display agent and a mining agent, whereby the latter is a synthesis of rough set theory and the fuzzy linguistic approach, enabling summarization of data, either based on fuzzy set theory [17] or by fuzzy dependencies [18]. The mining agent of this publication is based on fuzzy set theory, capable of organizing objects through disjunctive properties in those cases when a group of objects cannot be determined by unique features. According to [19] and [20] it is important to involve the human being in data mining. After a pre-mining process performed via a visual display agent, the user interacts with the system. Subsequently, "*the mining agent can automatically determine the property which most objects in a group have from the predefined properties*" [21]. For testing the model, data were collected on a 5 min basis and recorded hourly. After more than 180 trials the researchers obtained an accuracy of more than 93%. Despite this, the concept appears developable, since several suggestions for improvement were made.

B. Conclusion

Exact sciences are characterized by descriptions of quantities performed on precise investigation processes. A wide range of phenomena can be described by discrete or countable quantities resulting in 0 or 1 answers. This indicates, if an element A is belonging to a set M or not, which is referring to the classic set theory. However, in many cases, the application of precise numbers for characterizing continuous or uncountable quantities is questionable. Since there always remain a certain degree of uncertainty in measurement results, it is not useful to describe these results only with real numbers especially when introduced into stochastic models.

Decision finding and decision making processes are an important issue for managers both in governmental and economic institutions and depending on quantitative descriptions of investigated values and realistic information input. Since fuzzy numbers and the fuzzy set theory were introduced they became an interesting matter for applied sciences and how they can be a realistic input in stochastic modeling.

Soft computing applications such as fuzzy logic, neural networks and evolutionary computing have been providing helpful support in finance research. Several approaches implementing hybrid models consisting of stochastic and fuzzy components started to conquer financial prediction models.

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