Risk Management in the Electricity Market

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Abstract

As electricity products have the properties of significant volatility, no easy storage, and high elasticity of demand, the spot prices can be highly volatile over a certain period. To reduce the possibility of such uncertainty, electricity products need better risk management. One effective method is using financial instruments. In this paper, we will mainly discuss risk management by using derivatives and the adaptability of futures and forwards in the electricity market. For most investors, they prefer to hedge with a portfolio of derivatives. We will also explain Modern Portfolio Theory (MPT) to help readers understand how to use mathematical models to trade off risk and return.

Keywords: *electricity market; risk; management; derivatives; adaptability*

1.INTRODUCTION

With the continuous expansion of the electricity market, electricity products show a sharp upward trend. Now, the global power output is as high as 26,823,200 KWH. Under the influence of COVID-19, the electricity market initially experienced negative growth, but it has quickly returned to the track of sustained growth, with an annual growth rate of 3%-4%.The large amounts of funds being invested means that the electricity market is attracting more and more investors, and the fact that more people can profit from it also means that some people will have losses. One of the important losses is caused by the lack of risk management [1].

For example, under COVID-19, mentioned above, many participants will suffer a lot of losses because of this uncertainty. Therefore, in the face of such a booming electricity market, risk management is essential. Plenty of research has illustrated the methods of risk management by derivatives [2-11]. A number of studies at this stage discuss the importance of combining financial and electricity markets, with expenditure derivatives not only helping to hedge risk, but also enabling a price discovery function that allows the electricity market to present a reasonable range of commodities [11]. There is a lot of research at this point that shows that derivatives are very useful and important.

However, derivatives often behave differently in different product markets and are applied in different ways. The electricity product is unique, so whether these financial instruments are suitable for these products is worth investigating. The problems of the incomplete electricity market and what we can do to improve it are illustrated [8]. The article said that some derivatives aren't yet common in the electricity market, mostly because of the unique nature of electricity products. In this paper, we will first introduce the methods of risk management by derivatives and then discuss their adaptability in the electricity market. We will focus on adaptability by focusing on forwards and futures, comparing their characteristics and discussing their applicability in the electricity market. In addition, load-serving entities (LSEs) has now taken some measurements to improve the adaptability of derivatives. For example, the Delivery to Index Model helps reduce the basis risk existing in futures.These measurements will also be mentioned in this paper.

Since the combination of derivatives and electricity markets has not yet reached a mature stage, there are many aspects that need to be improved in the future. After talking about how adaptable electricity derivatives are, we'll also give some ideas for how to make the market more rational.

As most derivatives are now invested in portfolios to hedge , the question of how to seek to maximize the benefits of portfolio products becomes important. This paper will introduce Markowitz's Modern Portfolio Theory to address this issue. Modern portfolio theory (MPT) intends to portray the relationship between risk and return, using mathematical models to determine an asset's risk, quantifying the trade-off between risk and projected return, and finally construct an optimal asset portfolio.

Y. Jiang et al. (Eds.): ICEDBC 2022, AEBMR 225, pp. 1697–1702, 2022.
https://doi.org/10.2991/978-94-6463-036-7_254

The significance of this paper is in combining electricity markets and financial instruments, analyzing whether they are well integrated at this stage, and then proposing directions for future optimization. In addition, this paper doesn't show how to hedge each derivative on its own. Instead, it shows how to use a mathematical model to find the best balance between benefits and returns for the combined products.

Markowitz's Modern Portfolio Theory quantitatively explains how to maximize the benefits of portfolio investment with risk control. In fact, the use of MPT in the electricity market also requires some adaptations, and later on, we will also mention some extensions of the theory based on MPT, but it is still MPT in essence.

Last but not least, because the combination of electricity markets and financial instruments is not mature enough at this stage, and there are essential differences between electricity products and commodities, this paper will also give suggestions on how to solve these problems in the future.

2.Related Works

Nowadays, many articles have referred to the need for risk management in the electricity market, mainly highlighting the high volatility and demand elasticity of electricity products [1.3.5.7]. Uncertainty in the electricity market is the main factor in the need for risk management, but in addition to these two main factors, there are also factors that need to be considered, such as the stability of the power system and the safety and stability of the circuits during transmission, which can be risk factors in the electricity market. The majority of the articles emphasise risk factors that exist primarily in traditional trading while ignoring some of the lower probability but more serious consequence tail risks. The occurrence of tail risks can lead to large scale losses, so even if the probability of tail risks is small, they cannot be ignored.

So far, a lot of research has been put into electricity derivatives [2-5.8.9]. In the existing studies, researchers have described four derivatives: forwards, futures, options, and swaps [2-4]. These four derivatives are the basic products among hedging instruments, and by combining different derivatives, maximum returns within a certain risk range can be achieved. Many studies have only elaborated on the basic nature of these four derivatives separately, without considering whether all of them can be applied well in the electricity market. This paper will briefly introduce the types of derivatives and mainly focus on the comparison between forward and futures contracts and their adaptability in the electricity market.

In terms of how to hedge by portfolio, the current research suggests that the specificity of electricity products requires the construction of a power portfolio optimisation model based on Markowitz's modern portfolio theory [9]. However, most of the existing articles focus only on the mathematical formulation of the modern portfolio model and neglect the assumptions of the models. It's not just the formula for the modern portfolio model that we talk about in this paper, though.

The use of derivatives in the electricity market is limited, not widely used, thus constituting an incomplete derivatives market [7]. Some derivatives that cannot be used in large quantities because electricity products cannot be delivered in person. This is the main problems of the combination of electricity market and derivatives. This paper will analyse the adaptability of derivatives and propose future directions for optimisation to help build a more complete and rational electricity derivatives market.In this paper, we will discuss the adaptability of derivatives in the electricity market and the future direction of optimisation.

3.METHODS

3.1.Derivatives

In the electricity market, the use of derivatives for hedging is a good method of risk management. Derivatives can be divided into over-the-counter (OTC) and exchange traded. OTC derivatives are customized and have a large liquidity. However, as they are not strictly regulated, they are exposed to a higher risk of default. In contrast, exchange trading is more regulated in terms of the type, volume, and time of delivery. However, the liquidity is lower due to strict regulation and standardized contracts. Derivatives can be broadly classified into four categories: forwards, futures, swaps, and options. Of these, the vast majority of options and futures are traded over-the-counter, while forwards and swaps are traded over-the-counter.

3.2.Adaptability

After introducing the types and nature of derivatives, we discuss their adaptability in the electricity market. We mainly focus on the adaptability of forwards and futures. We compare the characteristics of forwards and futures, combined with the nature of electricity product trading. We found that forwards are more adaptable in the electricity market. In addition to the nature of the electricity product, the nature of the forward contract itself contributes to this problem, i.e. there is basis risk.

We have also looked at past data from the Mid-Columbia electricity market and found that the volume of forward contracts are indeed much greater than the volume of futures contracts traded.

However, this does not mean that futures have no role in the electricity market, as they can provide a more standardized contract that is more suitable for long-term, fixed-scale trading of electricity products.

We have also found that the derivatives market has taken some steps to address the poor adaptability of futures. In addition to this, some models are researched to address the need for futures to be more adaptable.

Finally, we also suggest some directions that can be optimized for the future of electricity derivatives, which we hope will help build a more rational and complete derivatives market.

3.3.Modern Portfolio Theory

MPT is also known as the mean-variance model. In this theory, the variance is used to measure the magnitude of risk and the arithmetic mean is used to measure the magnitude of return. The derivation of MPT involves a number of assumptions, which we will highlight in the Discussion section.

First, we construct the indifference curve by means of a utility function(1).

$$\mathrm{U} = \mathrm{E(R)} - 0.5\mathrm{A}\sigma^2 \tag{1}$$

Where A is the measure of risk aversion, U is the utility, E(R) the expected return .

The indifference curve describes the risk-return pairs of portfolio assets at a given utility level.

Secondly, on the basis of the mean-variance, We first derive the risk (2) and return(3) expressions for two combined assets.

$$R_p = R_1W_1 + R_2W_2 \tag{2}$$

$$\sigma_P = \sqrt{{W_1}^2{\sigma_1}^2 + {W_2}^2{\sigma_2}^2 + 2\sigma_1\sigma_2W_1W_2\rho_{12}} \tag{3}$$

Then we derive the return(4) and risk(5) for the portfolio consisting of N assets.

$$\mathrm{E}(\mathrm{r_p}) = \sum_{i=1}^{i=N} \mathrm{w_i}\, \mathrm{E}(\mathrm{r_i}) \tag{4}$$

$$\sigma_P = \sqrt{\sum_{i=1}^{i=N}\sum_{j=1}^{j=N} \mathrm{w_i w_j}\, \rho_{ij}\sigma_i\sigma_j} \tag{5}$$

After that, we construct the efficient frontier of the portfolio.

The tangent points of the upper convex efficient frontier and the lower convex undifferentiated curve of the asset are found to determine the optimal portfolio point.

We also find the current state of application of MPT theory in the electricity market. It shows that MPT theory is very useful in illustrating the correlation of different power in determining the optimal portfolios, while cannot precisely help investors find the optimal portfolio in the current market. Thus, MPT needs some adjustment and more consideration in electricity market. Also,we find that using MPT theory can help to obtain the optimal generation mix for Scotland, which indicates the good application of MPT in electricity market.

4.DISCUSSION

Due to the specific nature of electricity products, more and more market participants focus on the importance of risk management in the electricity market. This paper focuses on the following aspects: firstly, the application of derivatives in the electricity market and adaptability. Secondly, the modern portfolio theory helps make a trade-off between risk and return.

In the method section, we define the nature of the four derivatives, and next, we focus on their adaptability for use in the electricity market.

4.1. Derivatives

As mentioned above, derivatives can be divided into OTC derivatives and exchange-traded derivatives, depending on the delivery method. We will then briefly introduce each type of derivative. A forward contract is a contract in which the holders are obligated to acquire or sell an asset at a fixed delivery price at a future date. Futures are almost standardized forward contracts. While different to forward contracts, the exchange standardizes the terms and circumstances of futures contracts, such as the unit trading amount, delivery time and places, and so on, and the contract price.

An option is a contract that offers the buyer the right to purchase or sell at a specified price for a predetermined time. A premium is the monetary worth of the privilege to conduct a financial transaction.

A swap contract is between two parties to trade a series of cash flows generated by underlying assets in return for a fixed amount of money. There is no physical commodity exchanged between the buyer and seller.

4.2.Adaptability

Future contracts are specialized forward contracts that trade on a futures exchange. They have specific underlying assets, times to expiration, delivery and settlement conditions, and quantities. According to the Nordic power exchange[11], the hedging effect of futures in the power market is very significant. Still, the impact of direct arbitrage is not very substantial.

Although futures have a certain hedging function, it is not as adaptable as forward in the power market. The reason is that futures contracts are highly standardized, but the type and quantity of power products are highly personalized. Hedgers rarely find exactly matched futures contracts, which brings basis risk. Futures can only reduce the basis risk as much as possible, while forward can reduce the basis risk to 0.

Unlike financial and agricultural markets, where substantial price-affecting factors occur before the delivery time, significant unanticipated swings in both supply and demand can occur at high speed within the delivery period. As a result, the average spot price paid for power during the delivery month may differ significantly from the price at which the futures contract was closed. These characteristics greatly limit the standard futures contract's utility as a price risk management tool.

The trading volume of futures contracts in the electricity market is much smaller than that of forward contracts. S. J. Deng et al.[3] mentioned that Mid-Columbia electricity futures on the NYMEX provide 432 MWh of firm power supplied at 1 MW per hour, 16 on-peak hours per day, during the delivery month, whereas a related forward contract specifies 25 MW per hour. Although not traded on as large a scale as forwards, futures products are more liquid, more transparent, and have less risk of default.

In summary, compared to these two derivatives, forwards are more adaptable in the electricity market. However, forward contracts also face the problems of liquidity and high default risk. Nowadays, there is still a lot of search for ways to optimize the use of forwards or futures in the electricity market or try to combine the advantages of both and introduce combined derivatives. To combine the advantages of the two derivatives, LSEs are trying to combine futures and forwards to form a close match to long-term needs. However, most hedgers will still choose forward contracts for short-term, high-demand hedgers.

For the issue of basis risk in futures, R. A. Collins[11] has also constructed the Delivery to Index Model to reduce the basis risk; the average dollar mistake for the index delivery resettlement process is only $1.84, a 66% reduction from the present NYMEX contract. Compared to the current NYMEX contract, the average absolute percentage inaccuracy is 6.64 percent.

4.3.Modern Portfolio Theory

Modern Portfolio Theory (MPT) is a set of rules for analyzing and evaluating rational portfolio decisions regarding the risk[12].

First, H. M. Markowitz made several assumptions about the market and investors.

For the market, H. M. Markowitz assumed the market was a perfect capital market. First, there are no taxes or costs for the transaction. Secondly, all available information can be easily acquired by all traders. Thirdly, perfect competition exists among all market participants. Also, returns are assumed to be normally distributed.

For investors, H. M. Markowitz assumed all investors are risk-averse, which means investors prefer to obtain maximum return on a given risk level or minimize the risk for a given return.

After making the assumptions above, we can start to introduce MPT.

In MPT, the variance is used to measure the magnitude of risk, and the arithmetic means to measure the magnitude of return. In the mean-variance framework, we start constructing the portfolio. In MPT, we express the trade-off between risk and expected return by the utility function (1). Where U is the portfolio's utility, E(R) and σ^2 are the expected return and risk of a portfolio, respectively; A is an index of the investors' risk-aversion.

We assume that all investors are risk-averse, and A should be larger than zero. Next, we put E(R) to the left and others to the right and plot the curve of the utility function.

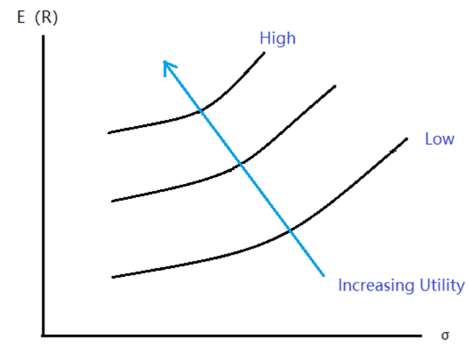

Figure 1. Utility function

Observing the curve, we find that investors want more returns to compensate for their risk with the increase in risk. Each curve is one indifference curve, which plots the combinations of risk and returns in pairs that investors can accept on a specific magnitude of utility.

First, we discuss the case of a portfolio P consisting of two assets: asset A and asset B. For the return of portfolio P, we express it as (2). Where R_p is the return of P, R1 is the return of asset A, R2 is the return for asset B, and W1 and W2 are the proportions invested in assets A and B.

For the risk of P, we express it as (3). Where ρ_{12} is the correlation coefficient of these two assets.

From the formulas for the return and risk of a two-asset portfolio, we can derive the formula for the return and risk of N assets.Return is expressed as (4), and risk is defined as (5).

As a result, we infer that the variance of a portfolio is influenced in part by the volatility of individual assets and in As a result, we infer that a portfolio's variance is partly influenced by the volatility of individual assets and, in part, by how they move together. The latter is calculated scientifically using the correlation coefficient or covariance of the portfolio's assets. The term describes the covariance, which explains why and to what extent diversification minimizes investment risk.

We construct an efficient frontier for the portfolio based on the risk and return equations for N risky assets.

As shown in the figure below, the effective frontier includes all combinations found in the market. Each point represents a portfolio, and its horizontal and vertical coordinates indicate the magnitude of its risk and return. The effective frontier provides the lowest risk for a given level of return and the highest return for a given level of risk.

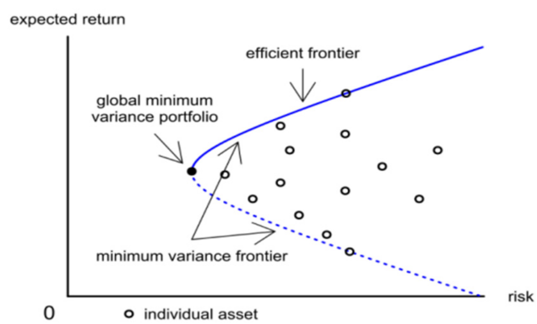

Figure 2. Effective frontier of portfolio

Then, the optimal portfolio is the point that is the tangent point of indifference curve to the effective frontier,shown in Figure 3 .

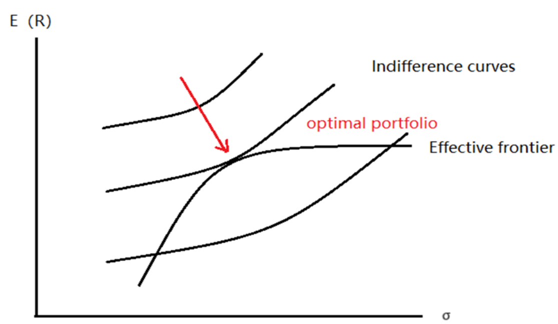

Figure 3. Optimal portfolio

MPT has been successfully applied in the power market. In terms of portfolio investment, it is worth pointing out that utilities must consider the risks that may impact their revenues while deciding on investment projects. The risks associated with power, fuel, and carbon costs become relevant in choosing the best product portfolios in this setting. In other words, MPT needs to be adjusted and applied in the power market.

At this stage, MPT can not help investors accurately confirm the optimal electricity portfolio in the market. Still, it can roughly provide investors with the direction of the optimal portfolio.

Research also shows that MPT can reveal the importance of the degree of correlation between electricity, fuel, and carbon prices in the definition of the optimal generation mix[9].

Therefore, how to optimize MPT theory in the future is a new research direction in the power derivatives market. In addition, MPT has been successfully used to find efficient power combinations in the power market. When looking for the best electricity generation mix in Scotland, MPT has been successfully used. In addition, the study also found that the power market has not reached the effective frontier by 2020, which shows that there is still a lot of room for the development of renewable energy in the power market from a financial point of view.

5.CONCLUSION

In conclusion, this paper discusses derivatives in the electricity market and their adaptability. We first introduced the types of derivatives and mainly focused on comparing the adaptability of forwards and futures. Also, we proposed some methods to enhance adaptability. Secondly, we analyzed the Modern Portfolio Theory and discussed how it applies to the electricity market. The importance of this paper is to combine the financial market and the electricity market to apply better risk management. More importantly, we analyzed adaptability based on historical data. There are still many aspects of the future use of derivatives in the electricity market that need to be investigated, such as whether the electricity derivatives market is still a rational market when the applicability of derivatives is limited. Regarding improving the adaptability of derivatives, we need to pay more attention to regional differences in electricity products and pricing and trading rules.

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