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Quantum and AI-based uncertainties for impact-relation map of multidimensional NFT investment decisions

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ABSTRACT

The purpose of this study is to identify the most essential determinants of NFT investments with a novel artificial intelligence based fuzzy decision-making model. First, the expert choices are prioritized with artificial intelligence methodology. Secondly, the criteria for multidimensional NFT investment decisions are weighted with Quantum picture fuzzy rough sets based DEMATEL. The findings denote that market trends and expected quality have the greatest weight. It is understood that customer satisfaction plays the most crucial role to increase the effectiveness of NFT investments.

1. Introduction

Non-fungible tokens (NFT) are digital certificates created using blockchain technology and used to denote digital assets. NFT investments also refer to investments made by purchasing these assets. These tokens represent digital assets in a unique way. Similarly, because blockchain technology is used, it is possible to trade these assets more securely. On the other hand, it may be easier to access the global market with these tokens. Due to these advantages, some actions need to be taken to develop NFT investments (Ali et al., 2023). First, the financial performance of these projects needs to be increased. Otherwise, the continuity of these investments will not be possible. Ensuring customer satisfaction is another element that should be taken into consideration in this process. The competitive advantage of projects will decrease significantly if customer expectations cannot be met (Nobanee & Ellili, 2023). Since these projects involve complex processes, it is also important for businesses to have sufficient technological infrastructure. This situation allows problems in business processes to be resolved quickly (Aharon & Demir, 2021; Akyildirim, Corbet, Sensoy, & Yarovaya, 2020).

Improvements regarding these factors mentioned above must be made to increase the effectiveness of NFT investments. However, these improvements also cause costs to increase. Therefore, it is not financially feasible for businesses to make too many improvements (Colicev, 2023). Hence, it is necessary for businesses to focus on the most important ones rather than improving all factors in terms of financial efficiency (Wang, Lee, Liu, & Hsu, 2023). It is necessary to identify key variables of NFT investments. However, there are a limited number of studies on this subject in the literature (Anselmi & Petrella, 2023; Boido & Aliano, 2023). In summary, a new study is needed to perform a priority analysis on performance indicators of NFT investments. Accordingly, the purpose of this study is to find

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the most critical determinants of NFT investments with a novel artificial intelligence based fuzzy decision-making model. In the first stage, the expert choices are prioritized with artificial intelligence methodology. Secondly, the criteria for multidimensional NFT investment decisions are weighted (An, Mikhaylov, & Chang, 2024; Chen, Tang, Yao, & Zhou, 2022; Chirtoaca, Ellul, & Azzopardi, 2020).

The main motivation of this study is a novel fuzzy decision-making model regarding NFT investment decisions. Most of the models in the literature cannot consider the weights of the decision makers. However, the qualifications of these people can be different based on their demographic factors. Hence, the main contribution of this study is the integration of artificial intelligence approach with the fuzzy decision-making methodology. With the help of this situation, the expert choices can be prioritized. As a result of this evaluation, a cluster analysis is performed among decision makers. The opinions of people outside this group may not be considered. Thus, it is possible to obtain more accurate analysis results (Aslam, Aziz, Nguyen, Mughal, & Khan, 2020; Borri, Liu, & Tsyvinski, 2022; Bouri, Cepni, Gabauer, & Gupta, 2021a,; 2021b).

On the other side, the proposed model has also some superiorities in comparison with the previously generated ones. The main contribution of this proposed model is that DEMATEL methodology is taken into consideration to weight the criteria. The performance indicators of NFT investments can have an impact on each other. Therefore, to find the most critical indicators, the causal directions of these factors should be considered. However, in the decision-making models with AHP and ANP, this relationship cannot be identified (Alkabaa et al., 2024; Khandelwal & Barua, 2024). In summary, DEMATEL is the most appropriate approach for the examination of this subject. On the other hand, this model was used by integrating the DEMATEL technique with Quantum picture fuzzy numbers. Thus, it is aimed to minimize the uncertainty problem in the process (Ante, 2022; Mikhaylov, 2023).

The proposed model can also be considered to solve real world problems. Real world problems are often complex and multidimensional. Using the DEMATEL approach, importance weights are calculated by taking into account the causality relationship between these factors. This contributes to achieving results by identifying the main causes of the problems. This allows the effectiveness of the results obtained to be increased. On the other hand, the use of Quantum picture fuzzy numbers in this proposed model also helps to manage uncertainty more successfully. In real world problems, uncertainty often exists. Therefore, to offer effective solutions to these problems, uncertainty must be reduced. Therefore, this proposed novel decision-making model contributes to a more effective analysis of these problems. In this context, this new model can be taken into consideration in many different industries. In this study, this model is proposed for the financial sector. Similarly, this model can also be taken into account when analyzing logistics, marketing and energy investments.

2. Methodology

In this study, a novel artificial intelligence based fuzzy decision-making model is constructed. There are two different stages of this model. The details are explained in the following subtitles.

2.1. Artificial intelligence-based decision-making for expert prioritization

In the first stage, the expert choices are prioritized by using artificial intelligence methodology. *Step 1* defines the specifications of the decision makers by employing the elbow method. The within-cluster sum of squares (WCSS) is computed for the different values of k as in Eq. (1) (Gao, Tao, & Cai, 2023).

$$WCSS = \sum_{j=1}^{k} \sum_{x_i \in C_j} d(x_i, c_j)^2 \tag{1}$$

In this process, k defines the number of clusters, C_j indicates the set of data points, x_i demonstrates a data point, c_j shows the cluster center and $d(x_i,c_j)$ explains the Euclidean distance between x_i and c_j.*Step 2* computes the optimal k value for clustering the decision makers. *Step 3* applies the K-means clustering algorithm for clustering decision makers via Eq. (2).

$$d(x_i, x_j) = \sqrt{\sum_{l=1}^{n} (x_{il} - x_{jl})^2} \tag{2}$$

In this process, n gives information about the number of dimensions. Cluster centers are updated with Eq. (3).

$$c_j = \frac{1}{|C_j|} \sum_{x_i \in C_j} x_i \tag{3}$$

Step 4 calculates the weights of the decision makers by considering the cluster weights. The mean standard deviation of each cluster is calculated as in Eqs. (4)–(6).

$$s_j = \frac{1}{n} \sum_{l=1}^{n} \sigma_{jl} \tag{4}$$

$$\sigma_{jl} = \sqrt{\frac{1}{|C_j|}\sum_{x_i \in C_j} (x_{il} - \overline{x}_{jl})^2} \tag{5}$$

$$\overline{x}_{jl} = \frac{1}{|C_j|}\sum_{x_i \in C_j} x_{il} \tag{6}$$

In this context, s_j defines the mean standard deviation, n denotes the number of dimensions and σ_{jl} refers to the standard deviation. The cluster weights w_j are computed by Eq. (7).

$$w_j = |C_j| \times s_j \tag{7}$$

The weights of the decision makers are defined with Eq. (8).

$$w_{tj} = \frac{1}{|C_j|} \frac{w_j}{\sum_{w_j \in C_j} w_j} \tag{8}$$

3.2. Quantum picture fuzzy rough sets based DEMATEL

The second stage consists of weighting the criteria for multidimensional NFT investment decisions by integrating Quantum fuzzy rough set with DEMATEL. *Step 5* defines the criteria for tourism company selection. *Step 6* collects the linguistic evaluations of decision makers for the criteria. *Step 7* constructs the quantum picture fuzzy numbers for the relation matrix as in Eq. (9) (Kou et al., 2023).

$$C_k = \begin{bmatrix} 0 & C_{12} & \cdots & \cdots & C_{1n} \\ C_{21} & 0 & \cdots & \cdots & C_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_{n1} & C_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{9}$$

Step 8 determines the quantum picture fuzzy rough sets for the relation matrix. The aggregated values can be computed via Eq. (10).

$$C = \begin{pmatrix} \left[min_{i=1}^{k}\left(\underline{Lim}\left(C_{\mu_{ij}}\right)\right), max_{i=1}^{k}\left(\overline{Lim}\left(C_{\mu_{ij}}\right)\right)\right] e^{j2\pi\cdot\left[min_{i=1}^{k}\left(\frac{\underline{\alpha}_{ij}}{2\pi}\right), max_{i=1}^{k}\left(\frac{\overline{\alpha}_{ij}}{2\pi}\right)\right]}, \\ \left[min_{i=1}^{k}\left(\underline{Lim}\left(C_{n_{ij}}\right)\right), max_{i=1}^{k}\left(\overline{Lim}\left(C_{n_{ij}}\right)\right)\right] e^{j2\pi\cdot\left[min_{i=1}^{k}\left(\frac{\underline{\gamma}_{ij}}{2\pi}\right), max_{i=1}^{k}\left(\frac{\overline{\gamma}_{ij}}{2\pi}\right)\right]}, \\ \left[min_{i=1}^{k}\left(\underline{Lim}\left(C_{v_{ij}}\right)\right), max_{i=1}^{k}\left(\overline{Lim}\left(C_{v_{ij}}\right)\right)\right] e^{j2\pi\cdot\left[min_{i=1}^{k}\left(\frac{\underline{\beta}_{ij}}{2\pi}\right), max_{i=1}^{k}\left(\frac{\overline{\beta}_{ij}}{2\pi}\right)\right]}, \\ \left[min_{i=1}^{k}\left(\underline{Lim}\left(C_{h_{ij}}\right)\right), max_{i=1}^{k}\left(\overline{Lim}\left(C_{h_{ij}}\right)\right)\right] e^{j2\pi\cdot\left[min_{i=1}^{k}\left(\frac{\underline{T}_{ij}}{2\pi}\right), max_{i=1}^{k}\left(\frac{\overline{T}_{ij}}{2\pi}\right)\right]} \end{pmatrix} \tag{10}$$

Step 9 computes the defuzzified values for the criteria by using Eq. (11).

$$Defc_i = \frac{\begin{pmatrix} \underline{Lim}(C_{\mu_i}) - \underline{Lim}(C_{n_i}) + \underline{Lim}(C_{\mu_i}) \cdot \left(\underline{Lim}(C_{v_i}) - \underline{Lim}(C_{h_i})\right) + \left(\frac{\underline{\alpha}_{ij}}{2\pi}\right) - \left(\frac{\underline{\gamma}_{ij}}{2\pi}\right) + \left(\frac{\underline{\alpha}_{ij}}{2\pi}\right) \cdot \left(\left(\frac{\underline{\beta}_{ij}}{2\pi}\right) - \left(\frac{\underline{T}_{ij}}{2\pi}\right)\right) + \\ \overline{Lim}(C_{\mu_i}) - \overline{Lim}(C_{n_i}) + \overline{Lim}(C_{\mu_i}) \cdot (\overline{Lim}(C_{v_i}) - \overline{Lim}(C_{h_i})) + \left(\frac{\overline{\alpha}_{ij}}{2\pi}\right) - \left(\frac{\overline{\gamma}_{ij}}{2\pi}\right) + \left(\frac{\overline{\alpha}_{ij}}{2\pi}\right) \cdot \left(\left(\frac{\overline{\beta}_{ij}}{2\pi}\right) - \left(\frac{\overline{T}_{ij}}{2\pi}\right)\right) \end{pmatrix}}{2} \tag{11}$$

Step 10 normalizes the relation matrix with the help of Eqs. (12) and (13).

$$B = \frac{C}{max_{1 \le i \le n}\sum_{j=1}^{n} C_{ij}} \tag{12}$$

$$0 \leq b_{ij} \leq 1 \tag{13}$$

Step 11 constructs the total relation matrix by Eq. (14).

$$T = \lim_{k \to \infty} \left(B + B^2 + \ldots + B^k\right) = B(I - B)^{-1} \tag{14}$$

Step 12 calculates the effects and the weights of the criteria. Eqs. (15) and (16) are considered to define cause (D) and effect factors (E).

$$D = \left[\sum_{j=1}^{n} e_{ij}\right]_{nx1} \tag{15}$$

$$E = \left[\sum_{i=1}^{n} e_{ij}\right]_{1xn} \tag{16}$$

Also, the impact-relation directions are represented by using a threshold value (α) via Eq. (17).

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left[e_{ij}\right]}{N} \tag{17}$$

3. Analysis

The analysis results of all stages are given in the following subsections.

3.1. Prioritizing the expert choices with artificial intelligence-based decision-making method (Stage 1)

In this stage, the first four steps are conducted by considering the Eqs. (1)–(8). Table 1 gives information about the details of the decision makers for different decision makers with education (Bachelor, Master, PhD), experience (18–20 years), salary (2400–2750 USD), age (40–45 years).

Table 1 explains that DM1 has the best education level because he has PhD degree. On the other side, DM5 and DM 6 have the master's degree. In addition to them, the working experience is quite similar for all people. Moreover, DM1 has the highest salary whereas DM4 has the lowest amount. In the following step, the values of the WCSS are computed for the different number of clusters. In this case, the number of clusters is 6, from 1 to 6, the set of WCSS values are presented for the different k values. Also, the elbow point is defined for selecting the optimal number of clusters for the dataset. According to the results, for $K = 3$, the WCSS value is minimized and optimized as adding more clusters will not significantly reduce the WCSS value. The optimal value for K number is applied for defining the clusters of decision makers. In this example, the optimal value of K is 3. The iteration results of different 3 clusters are given. The cluster assignment results are same with initial cluster centers and average of data points for iteration 1. Thus, the cluster of the decision makers is considered as DM1 is considered in cluster 1; DM2 and DM6 are listed in cluster 2; DM3 DM4, and DM5 are stated in cluster 3. It is seen that DM3, DM4 and DM5 have the best priorities with the value of 0.31 in the cluster 3. So, the evaluations of these 3 decision makers are considered only to assess the criteria and alternatives.

3.2. Weighting the criteria for multidimensional NFT investment decisions (Stage 2)

The analysis results of the steps 5–12 are presented in this section with the help of Eqs. (9)–(17). For this purpose, the criteria for NFT investment decisions are defined. Multidimensional factors of NFTs investment decisions are defined as financial real data (PRF: NFT profitability, LQD: NFT liquidity, RAT: NFT risk-adjusted returns), customer data (MTN: Market trends, SFF: Social effects, EQT:

Table 1
Specifications of the decision makers.

Decision maker (DM)	Education	Experience (year)	Salary (USD)	Age
DM1	3 (PhD)	20	2750	42
DM2	1 (Bachelor)	22	2600	45
DM3	1 (Bachelor)	20	2500	40
DM4	1 (Bachelor)	18	2400	41
DM5	2 (Master)	20	2500	42
DM6	2 (Master)	19	2600	40

Expected quality), internal process (RBL: Reliability, SCT: Smart contracts, RGS: Regulations), and data about learning and growth (INT: Innovative solutions, SLG: Self learning and steady education, SWW: Synergy with team working). Scales in Table 2 are taken into consideration with 3 scales of criteria (no, little, standard, effective, perfect).

Table 2 gives information about the scales, possibility degrees and fuzzy sets. There are five different scales that are no, little, standard, effective, and perfect. Similarly, five different possibility degrees are defined for each scale. In the rightmost column, the fuzzy numbers required for these values are given. The details of the linguistic evaluations of decision makers for each criterion are given in Table 3.

Table 3 gives information about the evaluations. Although there are five different decision makers, only three of them (DM3, DM4 and DM5) are taken into consideration as a result of artificial intelligence analysis. The evaluations of these people for 12 criteria are obtained. In this process, 132 questions are created by analyzing the causal relationship between these 12 criteria. 132 different questions are created by analyzing the relationship between 12 criteria. Since none of the criteria can be compared with each other, these values in the table are left blank. After that, the values are defuzzified and normalized. Finally, total relation matrix is created (An et al., 2020). The values in this matrix are considered to weight the criteria. The details of the total relation matrix and the weights are denoted in Table 4.

Table 4 demonstrates that market trends (C4) and expected quality (C6) have the greatest weight. On the other side, regulations have the lowest significant weight. This situation gives information that customer satisfaction plays the most crucial role to increase the effectiveness of NFT investment (Mikhaylov, Dinçer, Yüksel, Pinter, & Shaikh, 2023; Umar, Abrar, Zaremba, Teplova, & Vo, 2022a, ; 2022b; Urquhart & Lucey, 2022; Valeonti et al., 2021). Customer satisfaction increases customers' loyalty to the brand. Therefore, investors need to take the necessary actions to meet customer expectations. The important thing in this process is to clearly determine the expectations of different types of customers. To achieve this goal, a comprehensive analysis must be carried out. Since satisfied customers increase the brand's reputation, the sales volume of businesses can be increased. This significantly contributes to increasing the competitiveness of businesses. In this context, it would be appropriate to take some actions to increase customer satisfaction. First, communication with customers should be highly transparent. This increases customers' trust in the brand. On the other hand, different communication channels should be established to ensure that customers can easily communicate with the business. The satisfaction of customers whose questions are resolved quickly will increase significantly. Similarly, feedback from customers regarding services should be received at certain times. Thanks to this feedback, it is possible to clearly identify the flaws in the process. This allows solutions to these problems to be implemented in a timely manner.

4. Conclusion

In this study, it is aimed to define the most essential determinants of NFT investments with a novel artificial intelligence based fuzzy decision-making model. First, the expert choices are prioritized with artificial intelligence methodology. Secondly, the criteria for multidimensional NFT investment decisions are weighted. The findings demonstrate that market trends and expected quality have the highest weight. This situation explains that customer satisfaction plays the most crucial role to increase the effectiveness of NFT investments. The popularity of NFT investments increases especially in the last years. According to the reports created by Statista.com, the revenue in the NFT market is projected to reach 2.4 billion USD. Similar to this issue, it is also estimated that this revenue will exceed 3.4 billion USD. These figures show that NFT investments may have a very important place in the financial sector in the coming years. Therefore, taking the necessary measures to ensure customer satisfaction is of key importance to increase the success of these investors. The main limitation of the proposed model is that the weights of the experts are not calculated in this proposed model. However, the qualifications of the experts can be different according to their demographical factors. Therefore, in the following

Table 2
Scales for evaluation.

Scales for criteria	Possibility degrees	Fuzzy numbers
No (n)	0.40	$\begin{bmatrix}\sqrt{0.16}e^{j2\pi.0.4}, \\ \sqrt{0.10}e^{j2\pi.0.25}, \\ \sqrt{0.46}e^{j2\pi.0.22}, \\ \sqrt{0.28}e^{j2\pi.0.13}\end{bmatrix}$
Little (LTL)	0.45	$\begin{bmatrix}\sqrt{0.20}e^{j2\pi.0.45}, \\ \sqrt{0.13}e^{j2\pi.0.28}, \\ \sqrt{0.42}e^{j2\pi.0.17}, \\ \sqrt{0.25}e^{j2\pi.0.10}\end{bmatrix}$
Standard (STD)	0.50	$\begin{bmatrix}\sqrt{0.25}e^{j2\pi.0.50}, \\ \sqrt{0.15}e^{j2\pi.0.31}, \\ \sqrt{0.37}e^{j2\pi.0.12}, \\ \sqrt{0.23}e^{j2\pi.0.07}\end{bmatrix}$
Effective (EFV)	0.55	$\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55}, \\ \sqrt{0.19}e^{j2\pi.0.34}, \\ \sqrt{0.32}e^{j2\pi.0.07}, \\ \sqrt{0.19}e^{j2\pi.0.04}\end{bmatrix}$
Perfect (PFC)	0.60	$\begin{bmatrix}\sqrt{0.36}e^{j2\pi.0.6}, \\ \sqrt{0.22}e^{j2\pi.0.37}, \\ \sqrt{0.26}e^{j2\pi.0.02}, \\ \sqrt{0.16}e^{j2\pi.0.01}\end{bmatrix}$

Table 3
Linguistic evaluations of decision makers for the criteria.

DM3												
	PRF	LQD	RAT	MTN	SFF	EQT	RBL	SCT	RGS	INT	SLG	SWW
PRF		PFC	PFC	EFV	STD	LTL	LTL	STD	LTL	STD	LTL	STD
LQD	EFV		PFC	STD	LTL	LTL	LTL	LTL	LTL	LTL	LTL	LTL
RAT	PFC	EFV		STD	LTL	LTL	STD	LTL	LTL	STD	LTL	LTL
MTN	EFV	EFV	EFV		EFV	EFV	STD	STD	STD	EFV	EFV	STD
SFF	EFV	STD	STD	PFC		EFV	STD	LTL	EFV	EFV	STD	LTL
EQT	STD	STD	EFV	PFC	PFC		EFV	STD	LTL	EFV	EFV	EFV
RBL	STD	LTL	PFC	EFV	STD	STD		STD	LTL	LTL	LTL	LTL
SCT	LTL	EFV	STD	EFV	STD	STD	EFV		LTL	PFC	STD	STD
RGS	LTL	STD	EFV	EFV	STD	STD	EFV	EFV		STD	LTL	LTL
INT	STD	STD	LTL	EFV	STD	EFV	STD	PFC	LTL		STD	LTL
SLG	LTL	LTL	STD	STD	STD	EFV	EFV	LTL	LTL	STD		PFC
SWW	STD	LTL	LTL	STD	STD	EFV	STD	LTL	LTL	STD	PFC	
DM4												
	PRF	LQD	RAT	MTN	SFF	EQT	RBL	SCT	RGS	INT	SLG	SWW
PRF		EFV	EFV	EFV	STD	LTL	LTL	STD	LTL	STD	LTL	STD
LQD	EFV		EFV	STD	LTL	LTL	LTL	LTL	LTL	LTL	LTL	LTL
RAT	EFV	EFV		STD	LTL	LTL	STD	LTL	LTL	STD	LTL	LTL
MTN	EFV	EFV	EFV		EFV	EFV	STD	STD	STD	EFV	EFV	STD
SFF	STD	STD	STD	PFC		EFV	STD	LTL	EFV	EFV	STD	LTL
EQT	STD	STD	EFV	PFC	PFC		EFV	STD	LTL	EFV	STD	EFV
RBL	STD	LTL	PFC	STD	STD	STD		STD	LTL	LTL	LTL	LTL
SCT	LTL	EFV	STD	STD	STD	STD	STD		LTL	PFC	STD	STD
RGS	LTL	STD	EFV	EFV	STD	STD	EFV	STD		STD	LTL	LTL
INT	STD	STD	LTL	EFV	STD	EFV	STD	PFC	LTL		STD	LTL
SLG	LTL	LTL	STD	STD	STD	EFV	EFV	LTL	LTL	STD		PFC
SWW	STD	LTL	LTL	STD	STD	EFV	STD	LTL	LTL	STD	STD	
DM5												
	PRF	LQD	RAT	MTN	SFF	EQT	RBL	SCT	RGS	INT	SLG	SWW
PRF		PFC	PFC	EFV	STD	LTL	LTL	STD	LTL	STD	LTL	STD
LQD	EFV		PFC	STD	LTL	STD	LTL	LTL	LTL	LTL	LTL	LTL
RAT	PFC	EFV		STD	LTL	LTL	STD	LTL	STD	STD	LTL	LTL
MTN	EFV	EFV	EFV		EFV	EFV	STD	STD	STD	EFV	EFV	STD
SFF	EFV	STD	STD	PFC		EFV	STD	LTL	EFV	EFV	STD	LTL
EQT	STD	STD	EFV	PFC	PFC		EFV	STD	STD	EFV	EFV	EFV
RBL	STD	STD	PFC	EFV	STD	STD		STD	STD	LTL	LTL	LTL
SCT	STD	EFV	STD	EFV	STD	STD	EFV		LTL	PFC	STD	STD
RGS	LTL	STD	EFV	EFV	STD	STD	EFV	EFV		STD	LTL	LTL
INT	STD	STD	LTL	EFV	STD	EFV	STD	PFC	LTL		STD	LTL
SLG	STD	STD	STD	STD	STD	EFV	EFV	LTL	LTL	STD		PFC
SWW	STD	STD	LTL	STD	STD	EFV	STD	LTL	LTL	STD	PFC	

Table 4
Effects and the weights of the criteria.

	D	E	$D + E$	D-E	Weights	Priorities
PRF	17.074	17.395	34.469	−0.321	0.083	6
LQD	16.425	17.520	33.945	−1.094	0.082	10
RAT	16.677	17.898	34.575	−1.222	0.084	5
MTN	18.053	18.138	36.191	−0.085	0.088	1
SFF	17.571	17.1926	34.764	0.379	0.084	3
EQT	18.158	17.4436	35.602	0.714	0.086	2
RBL	16.873	17.2812	34.154	−0.408	0.083	7
SCT	17.406	16.7335	34.139	0.672	0.083	8
RGS	17.171	16.2409	33.412	0.930	0.081	12
INT	17.227	17.4765	34.704	−0.249	0.084	4
SLG	17.216	16.7688	33.985	0.448	0.082	9
SWW	16.903	16.6668	33.570	0.236	0.081	11

studies, a new decision-making model can be created while calculating the weights of the decision makers.

CRediT authorship contribution statement

Hasan Dinçer: Methodology, Investigation, Formal analysis, Data curation. **Serhat Yüksel:** Software, Resources, Project administration, Conceptualization. **Jaehyung An:** Writing – review & editing, Validation, Funding acquisition, Conceptualization. **Alexey Mikhaylov:** Writing – original draft, Visualization, Validation, Supervision.

Data availability

Data will be made available on request.

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References

Aharon, D.Y., Demir, E., 2021. NFTs and asset class spillovers: lessons from the period around the COVID-19 pandemic. Financ. Res. Lett. 47, 102515.
Akyildirim, E., Corbet, S., Sensoy, A., & Yarovaya, L. (2020). The impact of blockchain related name changes on corporate performance. *J. Corp. Financ.*, 65, Article 101759.
Ante, L., 2022. The non-fungible token (NFT) market and its relationship with bitcoin and ethereum. FinTech 1 (3), 216–224.
Ali, O., Momin, M., Shrestha, A., Das, R., Alhajj, F., Dwivedi, Y.K., 2023. A review of the key challenges of non-fungible tokens. Technol. Forecast. Soc. Change 187, 122248.
Alkabaa, A.S., Taylan, O., Guloglu, B., Baik, S., Sharma, V., Mishra, R., Upreti, G., 2024. A fuzzy ANP-based criticality analyses approach of reliability-centered maintenance for CNC lathe machine components. J. Radiat. Res. Appl. Sci. 17 (1), 100738.
An, J., Mikhaylov, A., Chang, T., 2024. Relationship between the popularity of a platform and the price of NFT assets. Financ. Res. Lett. 61 (3), 105057 https://doi.org/10.1016/j.frl.2024.105057.
An, J., Mikhaylov, A., Jung, S.-U., 2020. The strategy of South Korea in the global oil market. Energies 13 (10), 2491. https://doi.org/10.3390/en13102491.
Anselmi, G., Petrella, G., 2023. Non-fungible token artworks: more crypto than art? Financ. Res. Lett. 51, 103473.
Aslam, F., Aziz, S., Nguyen, D.K., Mughal, K.S., Khan, M., 2020. On the efficiency of foreign exchange markets in times of the COVID-19 pandemic. Technol. Forecast. Soc. Change 161, 120261.
Boido, C., Aliano, M., 2023. Digital art and non-fungible-token: bubble or revolution? Financ. Res. Lett. 52, 103380.
Borri, N., Liu, Y., & Tsyvinski, A. (2022). The economics of non-fungible tokens. Available at SSRN.
Bouri, E., Cepni, O., Gabauer, D., Gupta, R., 2021a. Return connectedness across asset classes around the COVID-19 outbreak. Int. Rev. Financ. Anal. 73, 101646.
Bouri, E., Saeed, T., Vo, X.V., Roubaud, D., 2021b. Quantile connectedness in the cryptocurrency market. J. Int. Financ. Mark. Inst. Money. 71, 101302.
Chen, J., Tang, G., Yao, J., Zhou, G., 2022. Investor attention and stock returns. J. Financ. Quant. Anal. 57 (2), 455–484.
Chirtoaca, D., Ellul, J., Azzopardi, G., 2020. A framework for creating deployable smart contracts for non-fungible tokens on the ethereum blockchain. In: 2020 IEEE international conference on decentralized applications and infrastructures. IEEE, pp. 100–105.
Colicev, A., 2023. How can non-fungible tokens bring value to brands. Int. J. Res. Mark. 40 (1), 30–37.
Gao, J., Tao, X., Cai, S., 2023. Towards more efficient local search algorithms for constrained clustering. Inf. Sci. 621, 287–307.
Khandelwal, C., Barua, M.K., 2024. Prioritizing circular supply chain management barriers using fuzzy AHP: case of the Indian plastic industry. Glob. Bus. Rev. 25 (1), 232–251.
Kou, G., Pamucar, D., Dinçer, H., Deveci, M., Yüksel, S., Umar, M., 2023. Perception and expression-based dual expert decision-making approach to information sciences with integrated quantum fuzzy modelling for renewable energy project selection. Inf. Sci., 120073
Mikhaylov, A., 2023. Understanding the risks associated with wallets, depository services, trading, lending, and borrowing in the crypto space. J. Infras. Policy. Dev. 7 (3), 2223.
Mikhaylov, A., Dinçer, H., Yüksel, S., Pinter, G., Shaikh, Z.A., 2023. Bitcoin mempool growth and trading volumes: integrated approach based on QROF Multi-SWARA and aggregation operators. J. Innov. Knowl. 8 (3), 100378 https://doi.org/10.1016/j.jik.2023.100378.
Nobanee, H., Ellili, N.O.D., 2023. Non-fungible tokens (NFTs): a bibliometric and systematic review, current streams, developments, and directions for future research. Int. Rev. Econ. Finance. 84, 460–473.
Umar, Z., Gubareva, M., Teplova, T., & Tran, D. K. (2022b). COVID-19 impact on NFTs and major asset classes interrelations: insights from the wavelet coherence analysis. *Financ. Res. Lett.*, 47, 102725.
Umar, Z., Abrar, A., Zaremba, A., Teplova, T., & Vo, X. V. (2022a). The return and volatility connectedness of NFT segments and media coverage: fresh evidence based on news about the COVID-19 pandemic. *Financ. Res. Lett.*, 49, 103031.
Urquhart, A., Lucey, B., 2022. Crypto and digital currencies—nine research priorities. Nature 604 (7904), 36–39.
Valeonti, F., Bikakis, A., Terras, M., Speed, C., Hudson-Smith, A., Chalkias, K., 2021. Crypto collectibles, museum funding and openGLAM: challenges, opportunities and the potential of nonfungible tokens (NFTs). Appl. Sci. (Switz.) 11 (21), 9931.
Wang, J.N., Lee, Y.H., Liu, H.C., Hsu, Y.T., 2023. Dissecting returns of non-fungible tokens (NFTs): evidence from CryptoPunks. N. Am. J. Econ. Finance. 65, 101892.