Fuzzy Set Approach to Evaluating the Effectiveness of Tax and Fee Administration*

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Abstract

The article examines the theoretical and methodological foundations as well as the applied dimensions of evaluating the effectiveness of tax and fee administration in Ukraine under conditions of digital transformation. Particular attention is given to substantiating the applicability of the fuzzy-multiple approach as an integrated assessment tool that accounts for the complexity, uncertainty, and nonlinear nature of fiscal processes. Based on official statistical data, the dynamics of key tax policy indicators are analyzed. This context made it possible to develop and test a fuzzy-multiple model for integrated assessment of the effectiveness of tax payment administration. To build the model, the influence of four main factors was taken into account, namely: Tax Administration Efficiency Ratio, Tax Debt, Level of Filing Declarations Using ICT and Tax Risk Management. Based on this approach, as well as taking into account the stimulating and disincentive effects of the above factors, a system of fuzzy inference rules was developed. It has been established that the digitalization of tax administration contributes to increasing its effectiveness, however, its effect depends on the level of tax compliance and the effectiveness of tax risk management. It has been proven that the growth of tax debt has a restraining effect, while the development of digital services creates the prerequisites for strengthening fiscal potential and stability of budget revenues.

Keywords

inance, budget, tax system, fuzzy-multiple approach, efficiency of tax payment administration, tax debt, digitalization, integral assessment, MATLAB, tax payment audit

1. Introduction

The current stage of fiscal policy transformation is characterized by the structural restructuring of the institutional configuration of the tax system, the increasing complexity of the architecture of inter-budgetary relations, as well as growing demands for transparency, adaptability, efficiency, and effectiveness in the administration of taxes and fees. Under these conditions, traditional approaches to assessing the effectiveness of tax administration are insufficiently sensitive to the multifactorial nature, uncertainty, and nonlinearity of fiscal processes, which necessitates the development and implementation of new methodological tools of analysis.

In this context, the application of the fuzzy-multiple approach becomes particularly relevant as a tool for the formalization of complex socio-economic phenomena, allowing for the integration of quantitative and qualitative evaluation parameters, taking into account data uncertainty and providing more flexible modeling of tax payment administration processes. The use of intelligent information technologies in combination with the apparatus of fuzzy logic creates the preconditions for increasing the validity of management decisions in the field of tax policy, particularly in terms of risk-based management, taxpayer segmentation, and the optimization of control procedures. The relevance of this study for Ukraine is significantly heightened by the

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conditions of the wartime economy, which are accompanied by high volatility of macro-financial indicators, growing fiscal risks, changes in the structure of budget revenues, and an increased burden on the system of tax and fee administration.

Recent research demonstrates that digital transformation significantly changes the architecture of tax administration through the implementation of electronic services, compliance-oriented tools, and data-driven decision-making mechanisms [6], [13], [17], [21]. Studies in this field show that digitalization can improve tax governance, transparency, and taxpayer interaction, although its impact depends on organizational quality, knowledge management, and risk-control capacity [8], [11], [21].

At the methodological level, many scholars have proved the effectiveness of fuzzy logic and intelligent systems for modeling complex processes under uncertainty [1], [2], [5], [10], [15]. These approaches are particularly suitable for multidimensional systems characterized by nonlinear relationships and heterogeneous indicators. In the tax domain, fuzzy and related logic-based methods have already been used to assess tax governance factors and specific tax-related phenomena [3], [4], [12], [20], but such studies remain limited in scope and do not offer an integral macro-level model of tax administration effectiveness.

For Ukraine, this issue is especially relevant due to wartime fiscal instability, digital transformation of public finances, and the need to strengthen the fiscal potential of the state [9], [16], [19]. Thus, despite a substantial body of literature on digital tax administration and fuzzy modeling, there remains a research gap regarding the development of an integrated fuzzy-set model that combines fiscal, digital, and behavioral indicators for assessing the effectiveness of tax and fee administration.

Scientific studies emphasize that the effectiveness of tax administration is formed under the influence of institutional, behavioral and digital factors, in particular the level of digitalization, the quality of the regulatory environment and the tax discipline of taxpayers [3, 14]. The fuzzy-multiple approach is used to evaluate complex socio-economic processes, in particular, the effectiveness of tax administration, risk management, and analysis of financial systems, where indicators are characterized by uncertainty, multifactoriality, and unclear boundaries between states [2, 12, 18]. In particular, the fuzzy-multiple approach is effective when modeling economic processes under conditions of uncertainty, in particular when estimating costs, demand, and making management decisions taking into account the influence of external factors and fuzzy parameters [5, 15].

The purpose of the article is to develop and test a fuzzy-multiple model of integrated assessment of the effectiveness of the administration of taxes and fees in Ukraine in the context of digital transformation, which is based on indicators of the implementation of budget revenues and the use of information technologies in order to develop ways of increasing the fiscal potential of the state in conditions of economic turbulence.

The article has the following structure – after the introduction, an overview of scientific sources on the digital transformation of tax administration and the application of fuzzy logic is presented, then the materials, research methods and methodological principles for building a fuzzy-multiple model are described, after which the results of its testing for assessing the effectiveness of tax and fee administration in Ukraine are presented, and the final sections are devoted to a discussion of the results obtained, conclusions, practical significance of the study and directions for further use of the proposed approach..

2. Materials and Methods

The study is based on official statistical information concerning the revenue performance of the Consolidated Budget of Ukraine, with particular emphasis on tax revenues, including both planned and actual figures. The research also uses data related to tax debt, the digital transformation of tax administration procedures and fees, and the dynamics of fiscal policy effectiveness. The empirical basis of the study was developed by organizing and summarizing the relevant data, which made it

possible to create a consolidated table of indicators for evaluating the effectiveness of tax payment administration in Ukraine.

The methodological framework of the research combines financial and economic analysis, a systems approach, and economic-mathematical modeling to evaluate the effectiveness of tax payment administration as a multifaceted component of public finance. The study applies statistical methods, including comparison, grouping, assessment of dynamics, and analysis of structural shifts, together with financial and economic evaluation of budget revenue formation indicators. In addition, economic-mathematical modeling based on fuzzy set theory is used to formalize the interrelations between fiscal, digital, and behavioral parameters of administrative efficiency. The fuzzy model was developed in the MATLAB environment using the Fuzzy Logic Toolbox in MATLAB R2018a by constructing a fuzzy inference system for the integrated assessment of tax payment administration effectiveness.

3. Case Study and Results

In the current context of the digital transformation of public finances, the administration of taxes and fees is acquiring the characteristics of a complex multi-level system, the functioning of which is determined by the interaction of institutional, information-technological, and economic factors. The expansion of the range of digital services, the integration of information platforms, and the use of analytical data-processing tools lead to increased requirements for the validity of assessing the effectiveness of tax administration, which, in turn, highlights the need to improve the relevant methodological tools.

At the same time, the growing role of information technologies in shaping the fiscal space is accompanied by increasing complexity in assessing the effectiveness of tax payment administration, since traditional approaches do not fully take into account the uncertainty, multicriteria nature, and nonlinearity of the relationships between the level of digitalization, tax compliance, and the amount of budget revenues [7]. Under these conditions, the development of integral evaluation models capable of combining multidirectional indicators into a single analytical structure is of particular importance.

In view of the above, it is advisable to use a fuzzy-multiple approach, which is based on an appropriate theoretical and methodological framework and makes it possible to formalize complex socio-economic processes under conditions of uncertainty. The use of such tools ensures the integration of indicators of budget revenue performance, the level of digitalization, and tax compliance parameters within the general assessment of the effectiveness of the administration of taxes and fees.

To determine the main tendencies and changes in the structure of tax payment administration, a consolidated analytical table was prepared, reflecting the dynamics of key indicators related to the Consolidated Budget of Ukraine. (Table 1) [19]. The analyzed data serve as the empirical foundation for developing a fuzzy-set model of integrated assessment and allow the interdependence between the digitalization of the tax environment and the effectiveness of fiscal outcomes to be examined. [16; 17].

The administration of tax payments aimed at generating the revenue side of the Consolidated Budget of Ukraine is of considerable importance for the financing of public services. In this regard, the assessment of tax administration effectiveness constitutes an important area for enhancing the efficiency and transparency of the tax system [13]. It should be emphasized that the tax revenue administration efficiency ratio reflects not only the performance of tax and customs authorities, but also broader trends in the development of the state's economic system. This coefficient is calculated as the ratio of actually collected tax revenues to planned tax revenues [8]:

$$\mathbf{R_tap}=\mathbf{\Sigma}TR_a/\mathbf{\Sigma}TR_p$$

where $\mathbf{\Sigma}TR_a$ – Actual tax revenues of the State Budget of Ukraine, billion UAH;

ΣTR_p – Planned tax revenues of the State Budget of Ukraine, billion UAH

Table 1
System of indicators for assessing the effectiveness of tax payment administration in Ukraine for the purpose of developing a fuzzy-multiple model

	2018	2019	2020	2021	2022	2023	2024	2025
Revenues of the Consolidated Budget of Ukraine, million UAH	1184278,1	1289779,8	1376661,6	1662242,7	2196273,3	3104306,6	3587789,5	4337978,2
Planned tax revenues, million UAH	989831,0	1112066,5	115481,4	1401890,0	1594058,1	1640424,2	2101712,6	2608754,3
Actual tax revenues, million UAH	986348,5	1070321,8	1136687,2	1453804,1	1343225,0	1638085,0	2088283,8	2520339,2
Tax administration performance ratio	0,996	0,962	9,843	1,037	0,843	0,999	0,994	0,966
Tax debt, million UAH	94751,3	116051,7	109404,5	93202,1	146604,9	138995,4	175740,7	238463,4
Submission of tax declarations using ICT, %	74,5	78,1	82,3	87,5	91,5	94,4	95,6	97

The considered system of indicators reflects the transformation of the effectiveness of tax payment administration in Ukraine during 2018–2025 and makes it possible to identify key structural trends in the functioning of the fiscal space. First of all, it should be noted that there has been a significant increase in budget revenues accumulated within the Consolidated Budget of Ukraine (by 3.7 times), which indicates an expansion of the revenue base but requires a comprehensive interpretation that takes into account inflationary, military, and institutional factors. At the same time, the analysis of the ratio of planned to actual tax revenues demonstrates the instability of the tax administration effectiveness coefficient: from a level close to unity in 2018 –2019 to overfulfillment in 2021 (1.037), followed by a further decline in 2022–2025 (to 0.843–0.966). The anomalous value of the indicator in 2020 also indicates the need for a critical interpretation of the initial data and for considering them as a source of analytical uncertainty [9]. In addition, the growth of tax debt (by 2.5 times) indicates the accumulation of fiscal imbalances and the deterioration of tax discipline, while the near-complete digitalization of tax declaration filing (up to 97%) creates institutional preconditions for improving the efficiency of administration.

To construct the fuzzy model, the MATLAB environment with the Fuzzy Logic Toolbox was used, as it provides a convenient tool for formulating rules, configuring membership functions, and visualizing results. The advantages of using this environment include the ability to model complex nonlinear dependencies [18], the visual representation of the fuzzy inference process, flexibility in setting model parameters [1], high accuracy of calculations [10], and the possibility of integration with other data analysis methods.

Compared to traditional statistical indicators, which usually assess the effectiveness of tax administration through individual quantitative indicators, such as the ratio of actual to planned tax revenues, the level of tax debt, or the share of electronic filing of declarations, the proposed fuzzy-multiple model has higher analytical value, since it allows not only to consider these indicators in isolation, but also to integrate them into a single evaluation system.

To describe linguistic variables, a trapezoidal membership function was used, which allows for a more accurate representation of the extreme values of the indicators and provides smooth transitions between intervals. The application of a fuzzy-multiple approach is appropriate for the assessment and prediction of indicators, as it enables the integrated processing of both quantitative and qualitative data within a single analytical framework. This is particularly relevant for evaluating the effectiveness of tax payment administration, because such indicators are shaped by a wide range of factors, demonstrate uneven dynamics, and depend on the level of digital transformation, taxpayers' compliance behavior, risk-based control mechanisms, and changes in tax legislation [4]. The proposed fuzzy inference system was developed using MATLAB R2018a. To evaluate the effectiveness of tax payment administration, four key factors were analyzed in detail, as they directly influence compliance-related outcomes: the share of tax revenues in the revenues of Ukraine's Consolidated Budget, the level of tax return submission through information technologies, the number of users of the taxpayer's electronic cabinet, and the level of tax compliance.

The general view of the proposed system is presented in Figure 1.

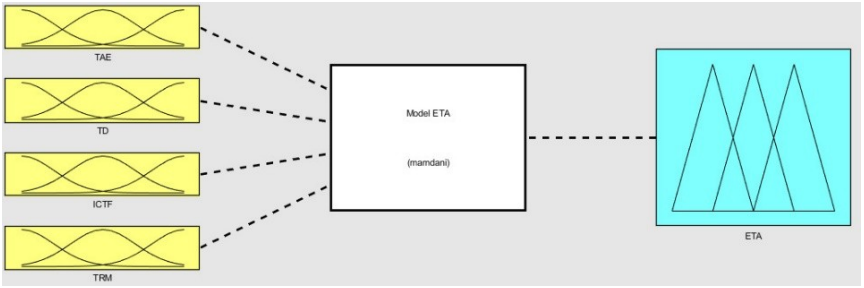


Figure 1: The general view of the fuzzy system of Effectiveness of tax payment administration

For model development, a trapezoidal membership function was applied, as it is appropriate in fuzzy modelling when linguistic variables such as "low", "medium" or "high" need to be represented with a clearly defined interval of stable class membership. This approach is particularly relevant for assessing the effectiveness of tax administration, since many of its indicators are characterized by normative ranges of acceptable values. The use of this membership function makes it possible to formalize linguistic terms related to tax administration performance indicators and to ensure the existence of a full membership interval, or plateau, that corresponds to normative or target values. Its advantage is that it allows you to identify an interval of stable values of the indicator within which a certain state can be considered fully formed.

All changes are within the interval from 0 to 1. For the construction of a fuzzy model, it means that the value 0 corresponds to the minimum level of manifestation. of the studied characteristic, while the value 1 – the maximum level. Intermediate values reflect the corresponding degrees of intensity or quality of the indicator. This approach allows for the generalization of heterogeneous economic indicators that have different units of measurement and scale, and their transformation. The table shows the threshold values for the linguistic variables "small", "medium" and "high", which are used to form the membership function of the variables in the model.

Table 2
The value of input indicators for building a tax administration assessment model

Variable	Designation	Type of impact	Small	Medium	High
Tax administration efficiency ratio	TAE	Stimulating	[0;0.35)	(0.25;0.75)	(0.65;1]
Tax debt	TD	Destimulating	[0;0.25)	(0.15;0.55)	(0.45;1]
Level of filing declarations using ICT	ICTF	Stimulating	[0;0.35)	(0.25;0.75)	(0.65;1]
Tax risk management	TRM	Stimulating	[0;0.30)	(0.20;0.70)	(0.60;1]

The tax administration efficiency (TAE) ratio reflects the ability of the tax system to ensure the completeness and timeliness of budget revenues, taking into account administrative costs. This indicator is used in the model as a stimulating variable, since as its value increases, the efficiency of tax administration increases. Figure 2 illustrates the overall shape of the membership function for the TAE variable.

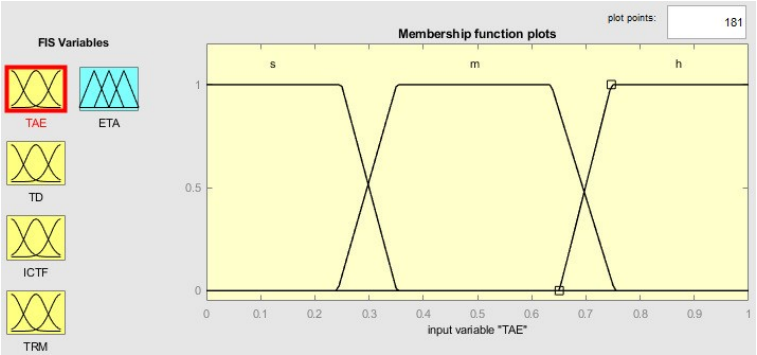


Figure 2: General view of membership functions of the variable TAE

Tax debt (TD) characterizes the level of taxpayers' debt to the budget and reflects the degree of fulfillment of tax obligations. In the model, this indicator is considered as a disincentive variable, since with an increase in its value, the efficiency of tax administration decreases. Figure 3 presents the overall configuration of the membership function for the TD variable.

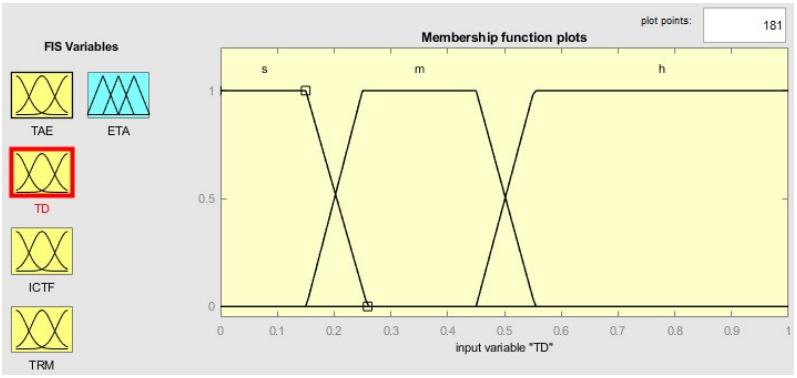


Figure 3: General view of membership functions of the variable TD

The ICT-based tax filing level (ICTF) reflects how extensively tax administration processes have been digitalized and how actively taxpayers use electronic services. In the model, this indicator is considered as a stimulating variable, since its growth contributes to increased transparency, timeliness of reporting and efficiency of tax information processing. Figure 4 shows a general view of the membership function of the ICTF variable.

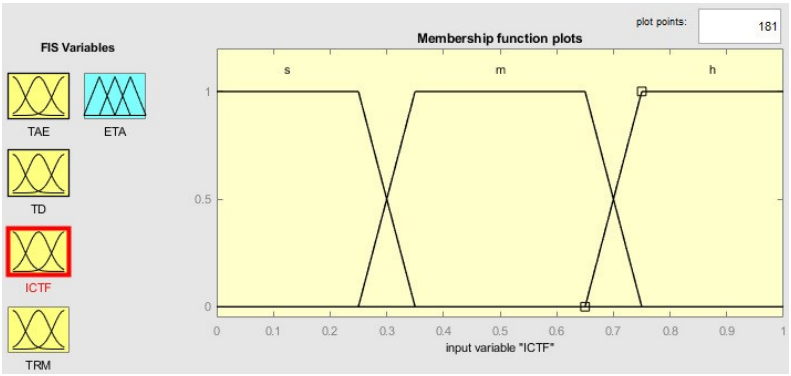


Figure 4: General view of membership functions of the variable ICTF

Tax risk management (TRM) characterizes the ability of tax authorities to timely identify, assess and minimize the risks of tax law violations and budget losses. In the model, this indicator is considered as a stimulating variable, since an increase in the level of risk-oriented management contributes to an increase in the efficiency of tax payment administration. Figure 5 presents the overall configuration of the membership function for the TRM variable.

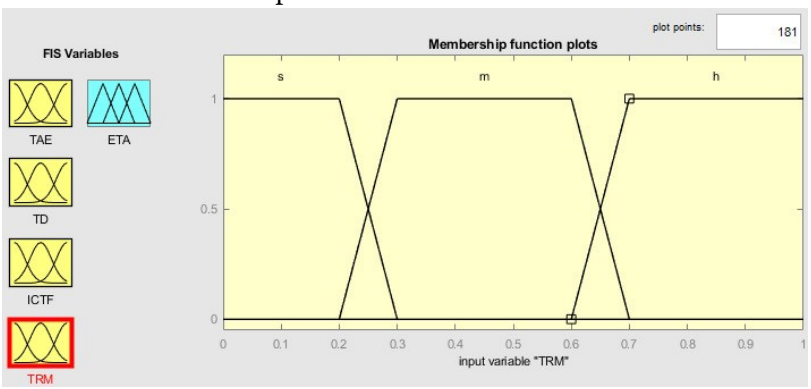


Figure 5: General view of membership functions of the variable TRM

The effectiveness of tax payment administration (ETA) characterizes the overall efficiency of the tax administration system by considering the completeness of tax revenues, taxpayers' compliance with fiscal obligations, and the quality of management of tax-related processes. Within the proposed model, this indicator serves as an integrated measure that combines the influence of several input variables.

For the ETA indicator, the following characteristics were established:

- low level $s \in [0;0.35)$;
- medium level $m \in (0.25;0.75)$;
- high level $h \in (0.65;1]$.

Figure 6 shows the general membership functions of the Model for assessing the effectiveness of tax payment administration (ETA).

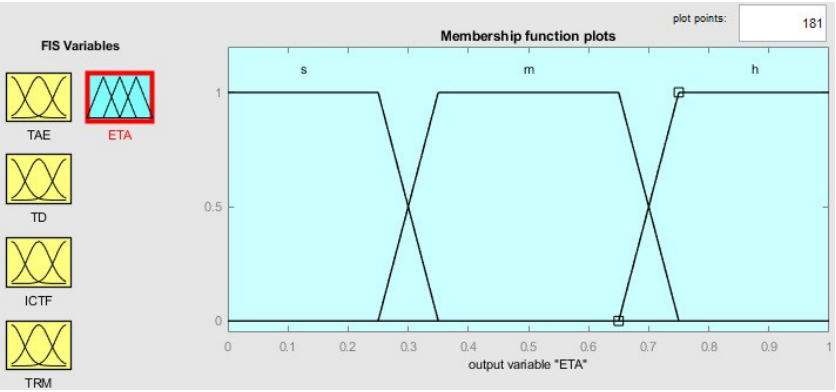


Figure 6: General view of the output result

To build a fuzzy model, 255 fuzzy inference rules were defined, which reflect possible combinations of input variable values and the corresponding levels of tax payment administration effectiveness. Each rule has the form of a logical construction of the "IF – THEN" type and reflects the relationship between the levels of input indicators and the corresponding level of tax payment administration effectiveness. Figure 7 presents an example of rule implementation and the corresponding output result.

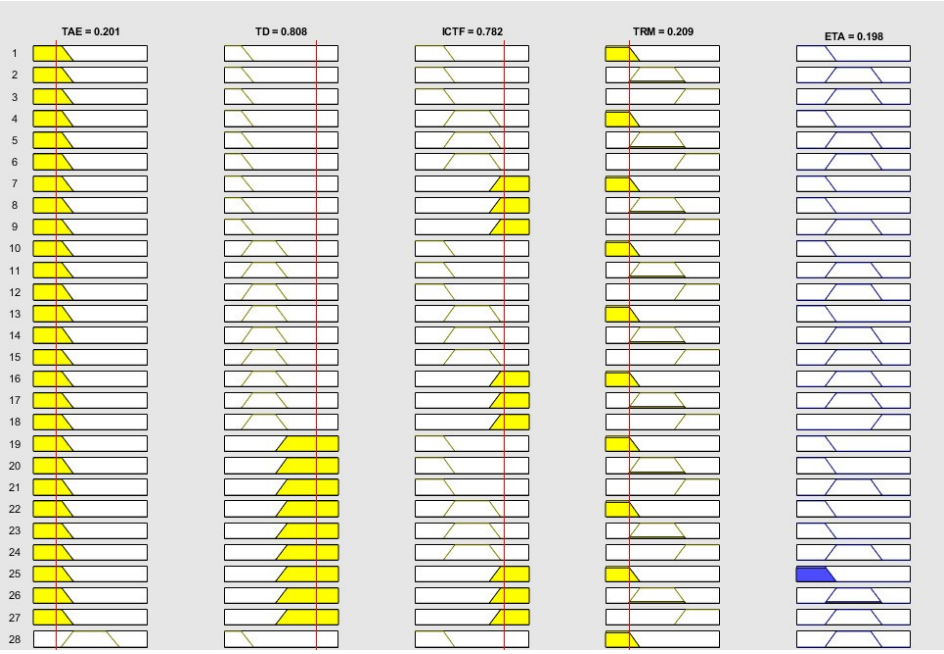


Figure 7: General view of the rules

Figure 8 shows the appearance of a fuzzy inference surface, which reflects the dependence of the efficiency of tax revenue administration on the input variables. The uneven shape of the surface confirms the nonlinear nature of the obtained result and the complex interaction of factors within the model.

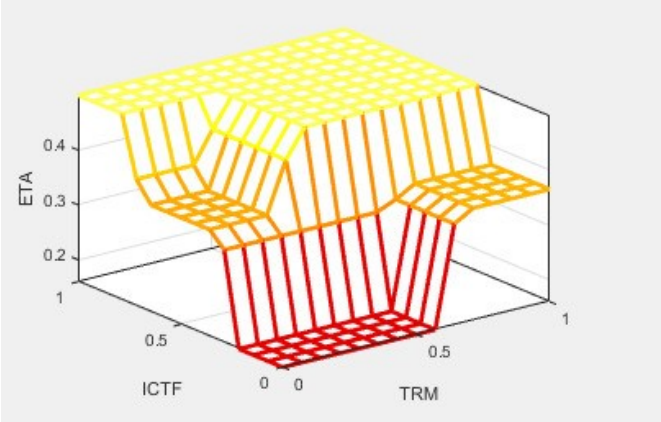


Figure 8: The surface of the dependence values of ICTF and TRM for Evaluating the Effectiveness of Tax and Fee Administration

4. Discussion

The obtained findings demonstrate that the fuzzy-set approach is appropriate for evaluating the effectiveness of tax and fee administration under conditions of economic complexity and uncertainty. In contrast to deterministic methods, this approach allows for a more flexible interpretation of indicators and takes into account the ambiguity inherent in socio-economic processes [6; 11], the proposed model allows integrating heterogeneous indicators (fiscal, digital, behavioral) and producing their nonlinear interaction, which is especially relevant in the conditions of a war economy. The results of the study revealed that the relationship between key indicators of administration performance management (performance ratios, tax debt, level of digitalization and tax risks) has a complex nonlinear nature. This confirms the limitations of traditional assessment approaches [20; 21], which do not take into account the ambiguity between the effective and ineffective state of tax administration.

It is emphasized that the digital transformation of tax procedures contributes to improving administrative effectiveness; however, its impact is not unconditional and is largely determined by the level of taxpayer compliance and the quality of risk management. At the same time, the growth of tax debt is a significant disincentive factor that reduces the overall effectiveness of the tax system. The methodological value of the study arises from the possibility of combining several statistical data and qualitative characteristics within a single model, which ensures its analytical flexibility and applied relevance. The use of trapezoidal membership functions made it possible to take into account the normative intervals of the value indicators and provide a more adequate interpretation of the results. However, the results of the study have certain limitations related to the sensitivity of the model to the quality of the input data and the provision of expert formation of the fuzzy inference rule base.

Conclusions

Thus, the proposed model makes it possible to integrate key indicators of tax administration effectiveness, in particular the administration efficiency ratio, tax debt, the degree of digitalization of administrative procedures, and the flexibility of tax risk management, into a single comprehensive assessment. Its application enhances the validity of analytical conclusions by taking into account the nonlinearity of relationships and the uncertainty of the economic environment.

The obtained results indicate that the digitalization of tax administration is an important driver of increased effectiveness; however, its impact is complementary to the level of tax compliance and the quality of risk-oriented management. At the same time, the growth of tax debt creates significant constraints on the realization of the state's fiscal potential, which necessitates the strengthening of preventive and stimulating mechanisms of tax policy.

The practical value of the research is determined by the possibility of applying the proposed model as an information and analytical tool to support the work of public administration authorities, particularly the Ministry of Finance of Ukraine and the State Tax Service of Ukraine. The model can be used to monitor the effectiveness of tax administration, improve the tax risk management system, and enhance the reliability of budget revenue forecasting. The integration of fuzzy-multiple models into the digital infrastructure of the fiscal space will contribute to the transition toward a data-driven approach to the formulation of fiscal policy.

The proposed fuzzy-multiple approach can also be applied in auditing practice, in particular for enhancing the analytical support of audit procedures, improving the assessment of tax-related risks, and increasing the reliability of audit conclusions under conditions of uncertainty.

Given the current challenges of the military economy and Ukraine's European integration priorities, it is important to focus on the institutional implementation of integrated indicators for evaluating tax administration effectiveness within the system for assessing the performance of tax authorities. In addition, greater attention should be paid to expanding the use of digital platforms and analytical instruments for real-time tax risk monitoring, as well as to improving mechanisms for managing tax debt.

Thus, the implementation of the fuzzy-multiple approach forms a methodological and applied basis for increasing the flexibility, adaptability, and effectiveness of tax and fee administration, which is critically important for ensuring the financial stability of the state and the effective implementation of fiscal policy in the conditions of modern transformations.

Declaration on Generative AI

During the preparation of this work, the authors used X-GPT to check grammar and spelling. After using this tool, the authors reviewed and edited the content as necessary and bear full responsibility for the content of the publication.

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