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Bahaaeddin Alareeni
Allam Hamdan *Editors*

Sustainable Finance, Digitalization and the Role of Technology

Proceedings of The International Conference on Business and Technology (ICBT 2021)

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Foreword

I am delighted to write this foreword for The International Conference on Business and Technology (ICBT 2021) proceedings. I deeply believe in the role of such a conference and other similar scientific forums in bringing together leading academicians, scholars, and researchers to share their knowledge and new ideas as well as to discuss current developments in the fields of economics, business, and technology. ICBT 2021 provides a valuable window on the implementation of technologies such as artificial intelligence, IoT, and innovation in business development. For two days, a large number of distinguished researchers and guest speakers discussed many contemporary issues in business and technology around the world. It is a great privilege for the College of Business and Economics at Palestine Technical University-Kadoorie, Palestine, to co-publish this book for the sake of promoting excellent and cutting-edge research by scholars from around the globe. I have a strong faith that this book will be of great benefit for many parties, especially those aspiring to develop buoyant strategies that will lead to positive impact on any future endeavors. Finally, I hope that the ICBT'21 continues as a destination for researchers, postgraduate students, and industrial professionals.

Khalid Sweis

Preface

The present business environment has been tumultuous due to the emerging new challenges resulting from innovative development and disruptive technology. Consumer demands for innovative products and services have urged business fraternity to be responsive and resilience in combating those new requirements.

The Fourth Industrial Revolution is characterized by the combination of physical and digital technologies, such as analytics, artificial intelligence, cognitive computing, machine learnings, and the Internet of Things (IoT). This would certainly impact the company's business direction, the future industries, the customers, the employees, and the society at large. The advancing technologies are bringing about social changes and economic development. As such, organizations are required to adapt to the new environment and strengthen their strategies despite the risk and uncertainty in the environment. New business integration strategies must be leveraged to ensure companies continue to sustain.

To anticipate the rapid change, education is set forth to be more innovative in offering the future ready curriculum. As such, education organizations and scholars are expected to be malleable and creative in designing new curriculum that embrace new technologies, integrating strong entrepreneurship values, fostering positive values and socio-emotional skills throughout the curriculum in order to produce quality and competent future human capitals that are ready to serve the future industries.

The integration between technology and business should be well managed so to provide a wide range of high-quality and competitive products and services in societies and countries. Therefore, the objective of this book proceedings is to conduct a review, examine, analysis, and discussion relating to the fields of business and technologies and their opportunities and challenges. We attempt to address a range of topics in the fields of technology, entrepreneurship, business administration, accounting, economics that can contribute to business development in countries, such as learning machines, artificial intelligence, big data, deep learning, game-based learning, management information system, accounting information system, knowledge management, entrepreneurship and social enterprise, corporate social responsibility and sustainability, business policy and strategic management, international management and organizations, organizational behavior and HRM, operations management and logistics research, controversial issues in management and organizations, turnaround, corporate entrepreneurship, and innovation, legal issues, business ethics, and firm governance, managerial accounting and firm financial affairs, non-traditional research, and creative methodologies.

This book constitutes the refereed proceedings of the International Conference on Business and Technology (ICBT 2021) organized by EuroMid Academy of Business & Technology (EMABT), held in Istanbul, between 06 and 07 November 2021. The ICBT 2021 partners and supporters were: Universiti Malaysia Kelantan–Malaysia; National University of Life and Environmental Sciences of Ukraine–Ukraine; ARCIF Analytics; E-MAREFA–Jordan; Palestine Technical University–Kadoorie, Palestine; and the Palestinian Community Association For Ph.D. Holders in the Public Service, Palestine.

In response to the call for papers for ICBT 2021, 485 papers were submitted for presentation and inclusion in the proceedings of the conference. After a careful blind-refereeing process, 292 papers were selected for inclusion in the conference proceedings from 40 countries. Each of these chapters was evaluated through an editorial board, and each chapter was passed through a double-blind peer-review process.

These chapters are reflecting quality research contributing theoretical and practical implications, for those who wise to apply the technology within any business sector. It is our hope that the contribution of this book will be of the academic level which even decision-makers in the various economic and executive levels will get to appreciate.

Finally, we express our sincere thanks to the plenary speakers; Prof. Carolyn Strong, Editor in-Chief, Journal of Strategic Marketing from Cardiff University-UK; Prof. Khaled Hussainey, Co-Editor in-Chief, Journal of Financial Reporting and Accounting, from University of Portsmouth-UK; Prof. Timothy Mescon, Executive VP and Chief Officer-Europe, Middle East and Africa at AACSB International AACSB International–USA; Prof. Roselina Ahmad Saufi from Universiti Malaysia Kelantan–Malaysia; Prof. Munira Aminova, Experienced Higher Education management leader with a demonstrated history of working in the research industry, from United Business Institutes-Belgium; Prof. Mohammad Kabir Hassan, Editor in-Chief, International Journal of Islamic and Middle Eastern Finance and Management, University of New Orleans-USA; and Prof. Derar Eleyan, President Assistant of Palestine Technical University Kadoorie-Palestine.

Bahaaeddin Alareeni
Allam Hamdan

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Corporate Finance, Digitalization of Accounting

CatBoost: The Case of Bankruptcy Prediction

Mário Papík, Lenka Papíková, Jana Kajanová, and Michal Bečka

Abstract Prediction of company bankruptcy is a field that develops mainly with the introduction of big data and data mining, and their application into actual business environment. In the field of classification methods, ensemble methods have significant position including various bagging or boosting algorithms. One of the newest algorithms in this field is the CatBoost algorithm developed in 2018. The aim of this manuscript is to apply the CatBoost algorithm to detect company bankruptcy based on financial and categorical data. The prediction model was created on a data sample of 89,447 small and medium-sized enterprises (out of which 295 went bankrupt) from Slovakia from the year 2019. The results indicate that the best CatBoost model achieved area under curve (AUC) value of 98.12%, and this model outperformed other models applying only financial or categorical variables. The contribution of this paper is the finding that application of categorical variables can contribute to better results than application of pure financial variables in CatBoost models. These findings should be taken into account by managers or institutions such as banks when creating their own bankruptcy prediction models.

Keywords CatBoost · Financial health · Bankruptcy prediction · Machine learning · Data mining

1 Introduction

Prediction of company financial health has undergone significant development over the last half-century. This development was conditioned by the development of computer technology and the large data volume to be processed. Due to this need to process large volumes of data, new methods (collectively called data mining) were developed. (Ringsdorf and Kajanová 2017). These methods use the computational performance of computers to search for helpful information hidden in data, thus replacing the originally applied statistical methods.

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The original bankruptcy models date back to the 60 s of the twentieth century. Authors of studies such as Beaver (1966) and Altman (1968), or authors of later studies from the 1980s (Ohlson 1980; Taffler 1984) generally applied univariate models, discriminant analysis or logistic regression to predict company bankruptcy. These models were primarily developed on balanced data samples: the size consisted of only 79 bankrupting companies in the case of Beaver study, 46 in the case of Taffler study or only 33 companies in the case of Altman study. Despite the limitations arising from the data sample size, these studies, together with other studies (Alareeni and Branson 2013) have shown that the financial situation of companies can be predicted based on financial variables.

With the new millennium, many authors began to take advantage of opportunities arising from the development of computer technology, large databases, and new classification methods. Classification methods like discriminant analysis or logistic regression have been replaced by methods such as support vector machine (Shin et al. 2005; Tang et al. 2020; Zelenkov et al. 2017), neural networks (Tang et al. 2020; Tumpach et al. 2020; Zhou et al. 2016), naïve Bayes (Liang et al. 2015; Zelenkov et al. 2017), decision trees (Tang et al. 2020; Zelenkov et al. 2017), k-nearest neighbours (Farooq and Qamar 2019; Liang et al. 2015; Liang et al. 2016) or random forest (Papík et al. 2020; Zelenkov et al. 2017). However, these methods have also encountered their limitations. The current trend in predicting bankrupting companies is the application of various ensemble methods such as different types of bagging or boosting algorithms. (Son et al. 2019; Tang et al. 2020; Wang et al. 2018; Zieba et al. 2016) These studies proved to be very robust in prediction even in the case of large, imbalanced samples, where bankrupting companies represented significant minor class.

One of the most recent studies in this area has shown the significant potential of boosting method CatBoost, (Jabeur et al. 2021). This method has significant advantages compared to those of other boosting algorithms (e.g. XGBoost). However, the Jabeur study only worked with financial variables, although one of the main advantages of CatBoost is its ability to work with categorical variables as well.

The aim of this manuscript is to apply the CatBoost algorithm to the prediction of company bankruptcy based on financial and categorical variables. The contribution of this paper is its determination whether the application of non-financial variables can also contribute to statistically better results than just the application of financial variables. The novelty of this manuscript consists of the fact that, so far, no other authors have used categorical variables in CatBoost to predict company bankruptcy.

This paper is structured as follows: the first part provides a literature overview, the second part describes the research methodology of the used data sample, features, CatBoost algorithm and methodological overview. The third section explains the results and discussion. Finally, the last part of this paper includes concluding remarks.

2 Literature Review

The current trend in the prediction of company bankruptcy uses various ensemble methods such as AdaBoost (Zhou et al. 2016; Zieba et al. 2016), XGBoost (Son et al. 2019; Tang et al. 2020; Zieba et al. 2016), LightGBM (Son et al. 2019), Grabit (Sigrist and Hirnschall 2019) or EXGB (Zieba et al. 2016). The authors of these studies generally demonstrated better performance of models that used one of these techniques than the performance achieved by logistic regression, neural networks, support vector machines, or random forest. Therefore, the literature review of this manuscript focuses on the ensemble methods.

Zieba et al. (2016) used an imbalanced sample of 700 bankrupting and 10,000 non-bankrupting Polish companies dating from 2000 to 2013. By application of several classification methods, this study showed that EXGB (AUC equal to 96%) outperformed other methods such as XGBoost with AUC 95% or AdaBoost with AUC at 92%. Therefore, all the above algorithms can be classified as boosting classification methods. Furthermore, the performance of these methods has shown their importance in the prediction of the financial health of companies in the future.

Zhou et al. (2016) researched almost 20,000 Chinese listed companies. As part of his study, Zhou did not directly address bankruptcy detection. However, he studied listing status. Listing status expresses the different levels of company risk. Unlike other studies, the Zhou research worked with four different risk categories in a company. Contrary to other existing studies, the best results in the Zhou study were not achieved by the boosting algorithm AdaBoost (this algorithm was the third-best with an accuracy of 87%), but the best results were achieved by the discriminant analysis (92%) and k-nearest neighbours (89%). These results could be caused by the need to solve a multi-class classification task.

Son et al. (2019), on a sample of 977,940 Korean companies (of which 23,137 went bankrupt), proposed an end-to-end data analytic approach to overcome issues in the company bankruptcy prediction area. This study included information on how to deal with missing values of outliers and highly skewed distribution. The best results among the five classification methods applied were achieved by XGBoost, with the value of AUC at 88%.

Tang et al. (2020) used a new approach to predict bankrupting companies in a balanced data sample with 424 Chinese companies. Instead of applying only financial and categorical variables, this study also focused on the possibilities to predict the financial health of companies through the words used in the company annual reports. The authors of this study showed that models combining all three types of variables achieved the best results. As only in a few studies, XGBoost achieved worse results than other alternative neural networks in the Tang study.

Sigrist and Hirnschall (2019) studied different sample sizes (100, 200, 2,000 and 10,000), different default ratios (1%, 2%, 10% and 20%) and their effect on the performance of the developed models. The study compared four classification techniques, out of which the Grabit model achieved the best AUC results. The results showed that the Grabit model could provide substantial and significant gains in levels of accuracy—for small sample sizes in particular. Furthermore, this model can also achieve increased levels of accuracy for datasets of moderate or large sizes.

Jabeur et al. (2021) compared several classification methods in a study of French companies from 2014 to 2016. The best results were achieved by CatBoost when compared to the results achieved by other applied methods such as XGBoost, GBN and neural network. CatBoost significantly exceeded the parameter of AUC compared to the AUC of other methods. As part of the Jabeur study, the authors also showed that it is possible to meaningfully predict a bankrupting company three years before the expected bankruptcy is declared. The limit of the Jabeur study was, in addition to a smaller data sample, that a smaller number of variables (18 financial variables) was used, and no classification variables were applied. Nevertheless, the AUC value the year before the bankruptcy was 99%, and the accuracy was 97%.

As the above overview of existing studies shows, the current trend of machine learning in the prediction of company bankruptcy is mainly the application of boosting algorithms such as XGBoost, AdaBoost, LightGBM or, more recently, CatBoost. In all mentioned existing studies, where these methods have been applied, except Tang et al. (2020), the results were better than results achieved by other machine learning algorithms (e.g. the neural network, support vector machine). Furthermore, the measured AUC values were mainly at the level of more than 88%, and the CatBoost algorithm is no exception, with an AUC value of almost 100% in a recently published study. Due to this reason, the aim of this paper is to apply the CatBoost algorithm to predict bankrupting companies by financial and categorical variables.

3 Research Methodology

The research methodology chapter is divided into the following parts: Sample details, Features, CatBoost and Methodological Overview.

3.1 Sample Details

Financial data of Slovak SMEs was collected for 2019. European Union recommendation no. 2003/361 defines SMEs as companies with a) number of employees below 250, and b) sales turnover below 50 million EUR or c) value of total assets below 43 million EUR. The data source of this paper was the Finstat database, which contains financial statements of companies operating in Slovakia. Overall, 89,742 financial statements were collected—89,447 of the SMEs have not reached bankruptcy event whilst 295 SMEs have experienced bankruptcy event.

Sector distribution of analyzed companies according to the NACE categorization is listed in Table 1, along with the default rate. A sector with the highest default rate is the Chemistry and plastics sector with a default rate of 1.79%. On the other hand,

Table 1 Sector distribution—NACE categories

Sector	Distribution %	Default rate %	Sector	Distribution %	Default rate %
Advertising	1.81	0.00	Intermediary activity	2.89	0.15
Agriculture and forestry	2.38	0.80	Law, consulting and accounting	6.98	0.16
Automobile industry	0.15	0.74	Media. publishing and culture	1.54	0.15
Clothing and footwear	0.59	0.94	Metalworking and metallurgy	2.71	0.90
Construction	12.32	0.53	Production—other	0.40	0.00
Development and civil engineering	3.37	0.17	Real estate	4.41	0.25
Education	0.99	0.34	Research and development	1.33	0.34
Electrical engineering	0.84	0.13	Retail	8.86	0.24
Energy and mining	0.63	1.41	Sales and maintenance of vehicles	2.27	0.10
Engineering	1.30	0.94	Service	5.44	0.10
Finance	1.89	0.12	Telecommunications	0.28	0.39
Food processing industry	1.24	0.99	Tourism and gastronomy	6.51	0.38
Gambling	0.15	0.75	Transportation and logistics	5.18	0.28
Health care	8.70	0.05	Waste management	0.47	0.71
Chemistry and plastics	0.69	1.79	Wholesale	7.47	0.40
Information technology	4.90	0.11	Wood and paper	1.32	0.59

Source: own source

Advertising sector has achieved a default rate of almost 0%. The default rate of the entire data sample is 0.33%, and therefore this data sample can be considered as significantly imbalanced against positive class (bankruptcy event).

3.2 Features

The collected data sample was used to calculate 26 financial ratios and 6 categorical variables. These variables are among the most frequently used variables in recent studies dealing with company bankruptcy. The list of these variables and their formulas are listed in Table 2. This study works with three sets of variables: a) all variables from Tab 2, b) 26 financial ratio variables, and c) six categorical variables. These three sets of variables are then compared against one another by the application of three different resampling methods.

Since the categorical variables are dataset specific, their explanation is provided in the following paragraph. For the industrial sector, there were 32 categories identified—they are further specified in Table 1. For the number of employees, there were three categories identified—micro (less than ten employees), small (less than 50 employees) and medium (less than 250 employees). All companies employed up to 250 employees because the data sample consists only of SMEs. In the case of organization forms, there were two categories—limited liability company and joint-stock company, one of the most common forms of business in Slovakia. The member of the board variable represented the number of management board members—the values running from 1 to 12. None of the management boards in the data sample had more than 12 members. Gender diversity variable was an indicator with two values. The gender diversity variable equalled 0 if no woman was represented in the management board and 1 if at least one woman was represented. As many as half of the companies had at least one woman represented within their management board. The last variable applied in this manuscript was the ownership which was represented by eight categories: cooperative society, international—private, international—public, private—domestic, statutory, owned by local government, foreign and church-owned.

3.3 CatBoost

This manuscript has applied the CatBoost method as the only classification method. CatBoost belongs to the gradient boosted binary trees. This algorithm aims to minimize the loss function of a model by adding weak learners using a gradient-descent like procedure. Unlike other gradient boosted methods, CatBoost can work with categorical features and looks for a very efficient optimal solution within its calculation. (Dorogush et al. 2018).

Since the CatBoost algorithm works with binary decision trees, output function *h(x)* has the following form (1):

$$h(x) = \sum_{j=1}^{J} b_j 1_{(x \epsilon R_j)} \tag{1}$$

Table 2 Financial and categorical features

Type	Financial ratio	Short name	Formula
Liquidity	Current ratio	CR	Current assets/Current liabilities
	Quick ratio	QR	(Current Assets—Inventories—Prepaid)/Current Liabilities
Leverage	Debt to Equity D/E ratio	DER	Total liabilities/Total shareholders' equity
	Total debt to assets ratio	DAR	Total liabilities/Total assets
	Long term debt to assets ratio	LDAR	Long-term liabilities/Total assets
	Shareholders' equity to assets	EAR	Total shareholders' equity/Total assets
	Loans to assets ratio	LOAN	Total loans/Total assets
	Interest coverage ratio	ICR	Earnings Before Interest Taxes/Interest expense
	Debt to EBIT ratio	FLR	Total Liabilities/Earnings Before Interest Taxes
	Debt to EBITDA ratio	DEBI	Total Liabilities/Earnings Before Interest Taxes Depreciation & Amortization
Profitability	Return on equity	ROE	Earnings Before Interest Taxes/Total shareholders' equity
	Return on assets	ROA	Earnings Before Interest Taxes/Total assets
	Return on sales	ROS	Earnings Before Interest Taxes/Total sales
	Return on investment	ROI	Earnings Before Interest Taxes/Cost of Investment
Efficiency	Asset turnover ratio	ATR	Net sales value/Average of total assets
	Receivables turnover ratio	RTR	Net sales value/Average of total receivables
	Inventory turnover ratio	ITR	Net sales value/Average of total inventory
	Fixed asset turnover ratio	FATR	Net sales value/Average of fixed assets
Growth	Receivable's growth	RG	(Receivables current year—Receivables previous year)/Receivables previous year
	Inventory growth	IG	(Inventory current year—Inventory previous year)/Inventory previous year
	Income from principal business operations growth	IPBOG	(Income from principal business operations current year—Income from principal business operations previous year)/Income from principal business operations previous year

(continued)

Table 2 (continued)

Type	Financial ratio	Short name	Formula
	Sales growth	SG	(Sales current year—Sales previous year)/Sales previous year
Other	Free cash flow (logarithm)	FCF	ln(Cash from Operations—Capital Expenditures)
	Working capital (logarithm)	WC	ln(Current assets—Current liabilities)
	Total assets (logarithm)	SIZE	ln(Total assets)
	Company age (logarithm)	AGE	ln(Company age)
Categorical	Industrial sector	SEC	32 categorical variables
	Number of employees	EMP	3 categorical variables
	Organisation form	ORG	2 categorical variables
	Member of board	BOAR	12 categorical variables
	Gender diversity in board	GEND	2 categorical variables
	Ownership	OWN	8 categorical variables

Source own source

where J represents the number of leaves, x corresponds to the explanatory variable, b_j is the predicted value in the disjoint region, and R_j corresponds to the tree's leaves. (Prokhorenkova et al. 2018).

So far, the CatBoost classification method has applied in the study of company financial health by Jabeur et al. (2021) but only for financial ratios. Financial health analysis through CatBoost using categorical variables has never been applied before. CatBoost calculation in this manuscript used functions from package "catboost" of version 0.16.5 in RStudio.

3.4 Methodological Overview

The methodological overview of this manuscript is shown in Fig. 1. The analytical process of this study consists of 1) collection of financial data from the Finstat database, 2) splitting sample into ten folds (nine folds for training sample and one fold for testing sample—this approach is repeated ten times with each fold used as a testing sample exactly once) 3) resampling of the training dataset (by three methods—no resampling, random oversampling and SMOTE), 4) transformation and scaling datasets 5) development of the CatBoost models, 6) model validation on testing datasets, 7) calculation of final average performance metrics through tenfold

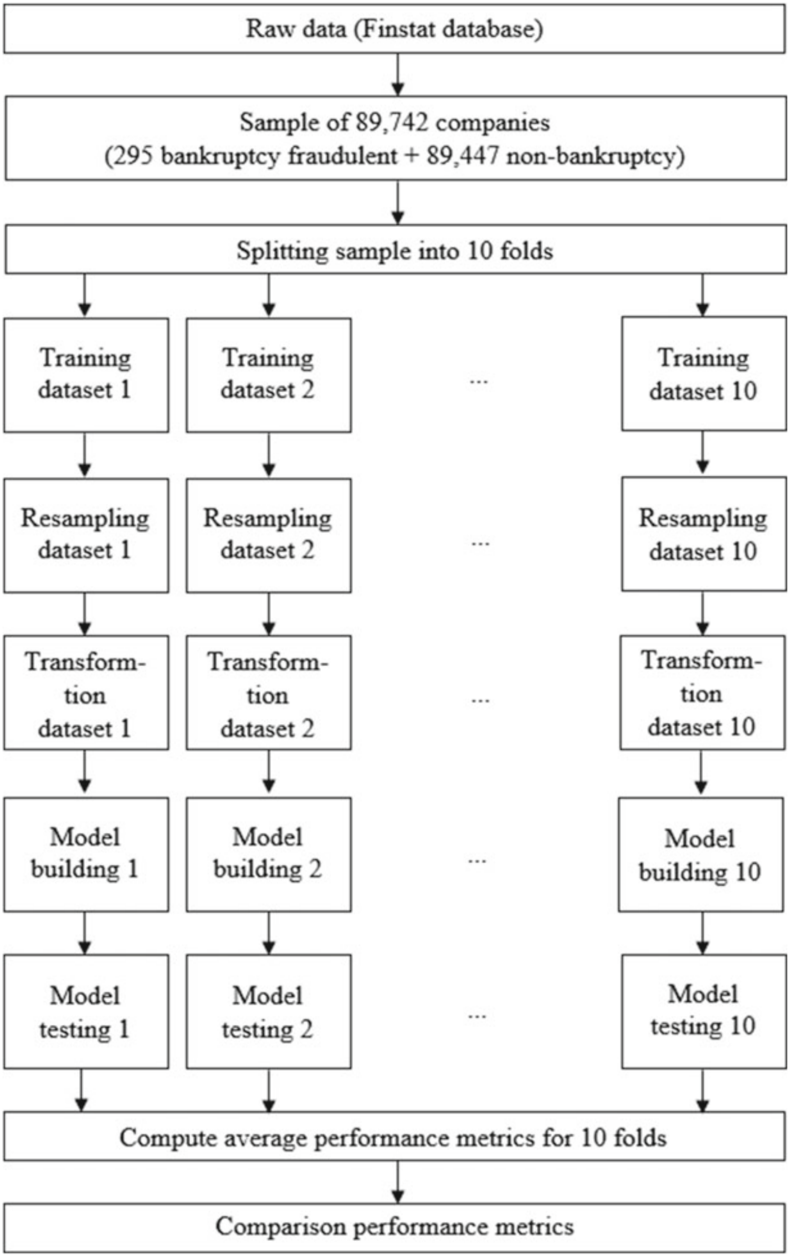

Fig. 1 Methodological overview

cross-validation and 8) comparison of performance metrics. tenfold cross-validation was also applied by other authors like Liang et al. (2015), Tang et al. (2020) and Wang et al. (2018). Studies to apply this approach achieve the most robust results and higher results of performance metrics.

This manuscript uses metrics of accuracy, sensitivity, specificity, and AUC as relevant performance metrics. Since the used data sample is highly imbalanced (295 to 89,447 companies), the AUC metric has been used as the main performance metric. In addition, AUC provides aggregate measurement of performance across all possible classification thresholds. Based on this metric, the best CatBoost model was identified across the individual datasets used (all features, only financial features, only categorical features) and the individual resampling methods (no resampling, random oversampling, SMOTE).

4 Results and Discussion

Results obtained in this manuscript can be divided into three parts—descriptive statistics, evaluation of the importance of used features, and evaluation of the performance metrics for particular feature samples and resampling methods.

Table 3 provides an overview of the descriptive statistics for the financial ratios used in this manuscript. Descriptive statistics (median and standard deviation) are divided according to whether a company declared bankruptcy or not. Statistically significant differences among medians were tested by the Kruskal–Wallis test. Significant differences between groups were observed only among the variables: Current ratio (CR), Quick ratio (QR), Asset turnover ratio (ATR), Receivables turnover ratio (RTR), Fixed asset turnover ratio (FATR) and Receivable's growth (RG). As shown, the companies declaring bankruptcy have achieved statistically significantly lower values in all the above indicators, which can be explained by the decrease in their liquidity and efficiency.

Relative feature importance in the form of a box plot achieved on all ten folds and three resampling methods (30 measurements) is shown in Fig. 2. Figure 2 shows that among the ten features with the highest relative feature importance, six can be classified as leverage ratios and two as profitability ratios. Therefore, it can be assumed that the unfavourable financial situation of a company can be predicted based on its level of debt and ability to generate profit. The feature importance gained from CatBoost thus differs from the differences identified through the Kruskal–Wallis test (mainly the liquidity and efficiency ratios). These results also contradict the study by Jabeur et al. (2021), which considered profitability and liquidity ratios as the most relevant features to detect problems in a company's financial health.

As far as categorical variables are concerned, the greatest relative importance has been achieved by the classification of a company into an industrial sector. Nevertheless, the relative feature importance for this variable is within the weaker half of all features. The relative feature importance of the other categorical features was one of the lowest among all the tested variables. Number of employees, organization form,

Table 3 Descriptive statistics

Feature	No bankruptcy		Bankruptcy		Krusk.- Wall. t	P-value
	Median	St.dev.	Median	St.dev.		
CR	0.55	183.59	0.33	3.19	0.006	**
QR	0.84	458.22	0.60	3.21	0.049	*
DER	0.69	18,577.60	0.25	53.93	0.291	
DAR	0.60	89.88	0.95	122.21	0.059	
EAR	0.40	89.88	0.05	122.21	0.059	
LDAR	0.00	6.06	0.02	12.49	0.102	
LOAN	0.00	0.70	0.00	8.88	0.155	
FLR	1.70	18,577.60	1.25	55.10	0.292	
ICR	100.00	11,450.69	3.99	20,352.53	0.111	
DEBI	2.17	29,241.63	−0.48	333.89	0.406	
ROE	0.12	74.57	0.09	9.09	0.201	
ROA	0.04	30.29	−0.04	120.07	0.115	
ROS	0.03	134.96	−0.05	217.45	0.669	
ROI	0.04	30.28	−0.03	119.15	0.118	
ATR	1.57	55.88	0.76	2.37	0.000	***
RTR	7.76	7365.48	3.44	212.75	0.001	***
ITR	1.90	44,326.19	3.68	2554.11	0.040	
FATR	3.39	19,133.43	1.54	179.24	0.013	*
RG	0.06	417.02	−0.18	1.22	0.000	***
IG	1.00	176.04	0.00	2531.27	0.329	
IPBOG	−0.18	867.09	−0.48	240.38	0.338	
SG	0.05	4943.88	−0.18	2.34	0.226	
FCF	−0.27	63.81	−0.03	50.87	0.986	
WC	0.30	86.48	−0.05	109.45	0.091	

Source: own source based on calculation in RStudio

members of the board, gender diversity in the board or company ownership did not have any significant impact on whether the company will declare bankruptcy in the coming year or not.

Table 4 contains achieved values of performance metrics for created CatBoost models on three feature samples and three resampling methods. Based on results of AUC metrics, it can be assumed that a) the best model achieved AUC of 98.12% with random oversampling, and both financial and categorical variables b) random oversampling overcame values of both SMOTE and no resampling approach c) the combination of financial and categorical variables has always achieved better results than just financial variables—this does not apply to no resampling approach—but this difference was not statistically significant d) for the application of only six categorical variables, AUC was at least 60.95% level, and application of data resampling has

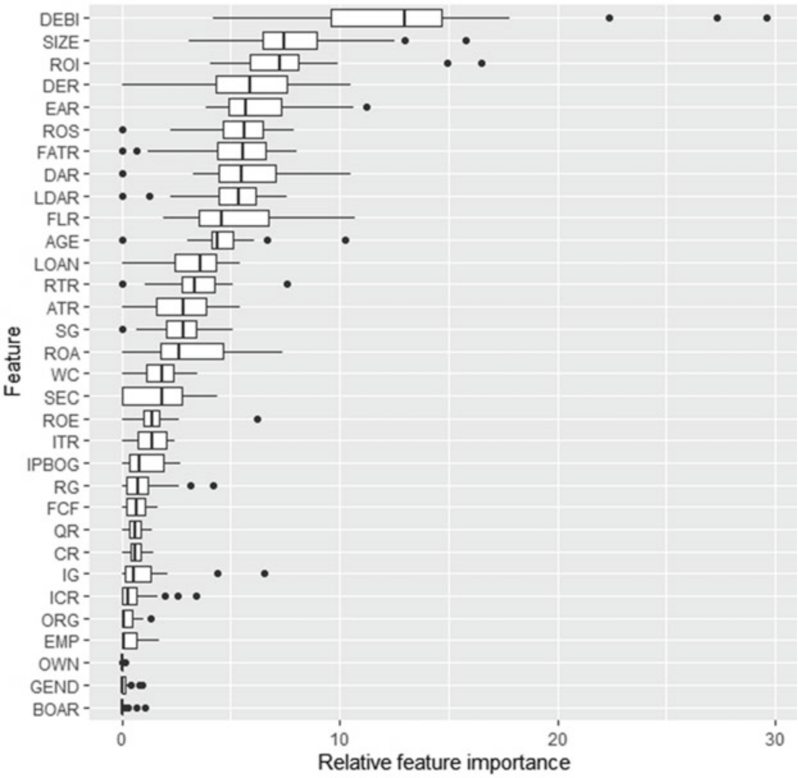

Fig. 2 Relative feature importance by CatBoost

Table 4 Performance metrics for CatBoost

Resampling	Features	Accuracy	Sensitivity	Specificity	AUC	Sign
Without resampling	Categorical	65.25%	51.70%	65.31%	60.95%	***
	Financial	96.03%	90.01%	96.05%	96.80%	
	Both	93.68%	92.34%	93.68%	96.30%	
Random oversampling	Categorical	66.60%	74.23%	66.57%	73.23%	***
	Financial	93.27%	95.44%	93.27%	97.77%	
	Both	94.79%	93.64%	94.79%	98.12%	
SMOTE	Categorical	69.71%	67.42%	69.72%	72.11%	***
	Financial	93.75%	94.78%	93.75%	97.71%	
	Both	95.16%	93.15%	95.17%	98.00%	

Source: own source based on calculation in RStudio achieved values up to 72.11%. These results are comparable to the study by Jabeur et al. (2021), in which the AUC of the developed CatBoost model was 99.4% and accuracy 97.4%.

5 Conclusion

The aim of this manuscript was to apply the CatBoost algorithm to the prediction of company bankruptcy based on financial and categorical data. This manuscript has brought the following five findings: 1) there is a difference in the selection of relevant features based on standard mathematical techniques (Kruskal–Wallis test) — liquidity and efficiency ratios were preferred—and based on data mining techniques (CatBoost) —leverage ratios were preferred; 2) out of all categorical features, the most relevant variable was the classification into the industrial sector, other categorical variables were not relevant 3) combination of categorical and financial ratios in CatBoost models can bring better results, but these results are not statistically significantly better, 4) CatBoost model developed on resampled data sample achieves better performance metrics than the model not created on resampled data sample, and 5) CatBoost achieves very interesting results even on large data samples (accuracy 94+ %, AUC 98+ %). Based on these findings, we can conclude that CatBoost models have the potential to achieve high predictive performance. This performance is even slightly better when categorical variables are used. However, the vast majority of these variables make only a small contribution to the improvement of the created models' performance metrics. These findings should be considered by managers or institutions such as banks when creating their own default prediction models.

This manuscript, however, also has its limitations. The first limitation is the composition of the data sample, which consists of Slovak small and medium-sized enterprises. The data sample structure across industrial sectors copies the representation of these sectors in the Slovak economy and information about relevant features can only be transferred to comparable small open economies in Central and Eastern Europe. The second limitation is the range of used categorical variables. The ratio between financial and categorical variables was 28:6 and thus, financial variables significantly dominated over the categorical variables. Possible improvement of the prediction model with all variables compared to the model with only financial variables could have been more significant had the sample with categorical data contained more variables. The last limitation can be the blackbox character of the developed model. While in the case of Altman's Z-score, there is easily applicable equation, in the case of findings of this manuscript, only information about the performance metrics of the developed model is provided. This partially complicates the possible cross-validation of these findings on other datasets.

This study does not cover all areas of possible future research. Future studies could therefore focus on the application of CatBoost to data samples from other countries (large economies like the USA or China) or financial statements prepared with different periodicity (e.g. quarterly financial reports). It is also recommended