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**Predicting bankruptcy among Polish companies
using logistic regression**

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subject during Data Science studies

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INTRODUCTION

Bankruptcies among companies were and still are widely discussed because of their impact on the economy. In fact bankruptcies have both good and bad influence on the macroeconomic situation – on one hand its' occurrences result in loss of jobs and create market uncertainty¹ (especially when bigger company defaults) but on the other hand it is an instrument of clearing the market from redundant firms.² Although it may be useful, most of the market participants would rather know when certain company might “go down”. Focused efforts by economists and statisticians, that began in the thirties, effected in variety of tools designed to work as a precautionary mechanisms. However, prediction accuracy of these tools, especially econometric models, is often questioned. Considering Poland, most of the approaches from literature³ used to predict company bankruptcy are based on the discriminant analysis (such as Altman's model) and logistic regression (such as Ohlson “O-score”). Also data used in those examples is not sampled – it is mainly based on finding every existing bankrupt company in the population and randomly attaching same number of healthy companies.

Main goal of our paper is to determine whether it is possible to create prediction model that gives reasonable company bankruptcy predictions on unbalanced data (in which bankrupt companies make only 3% of the whole dataset – as it is far more realistic scenario) in great advance (5 years prior to bankruptcy) using logistic regression. Afterwards we try to compare it to model 1 year prior to default. If models appear to be applicable then we want to examine which accounting variables are the main determinants of these bankruptcies (and whether these determinants differ between models).

¹ Carter R., Van Auken H.: *Small Firm Bankruptcy*. Journal of Small Business Management 2006 44(4), 2006, pages 493–512

² Mączyńska E., Zawadzki M.: *Dyskryminacyjne modele predykcji bankructwa przedsiębiorstw*. Ekonomista 2/2006.

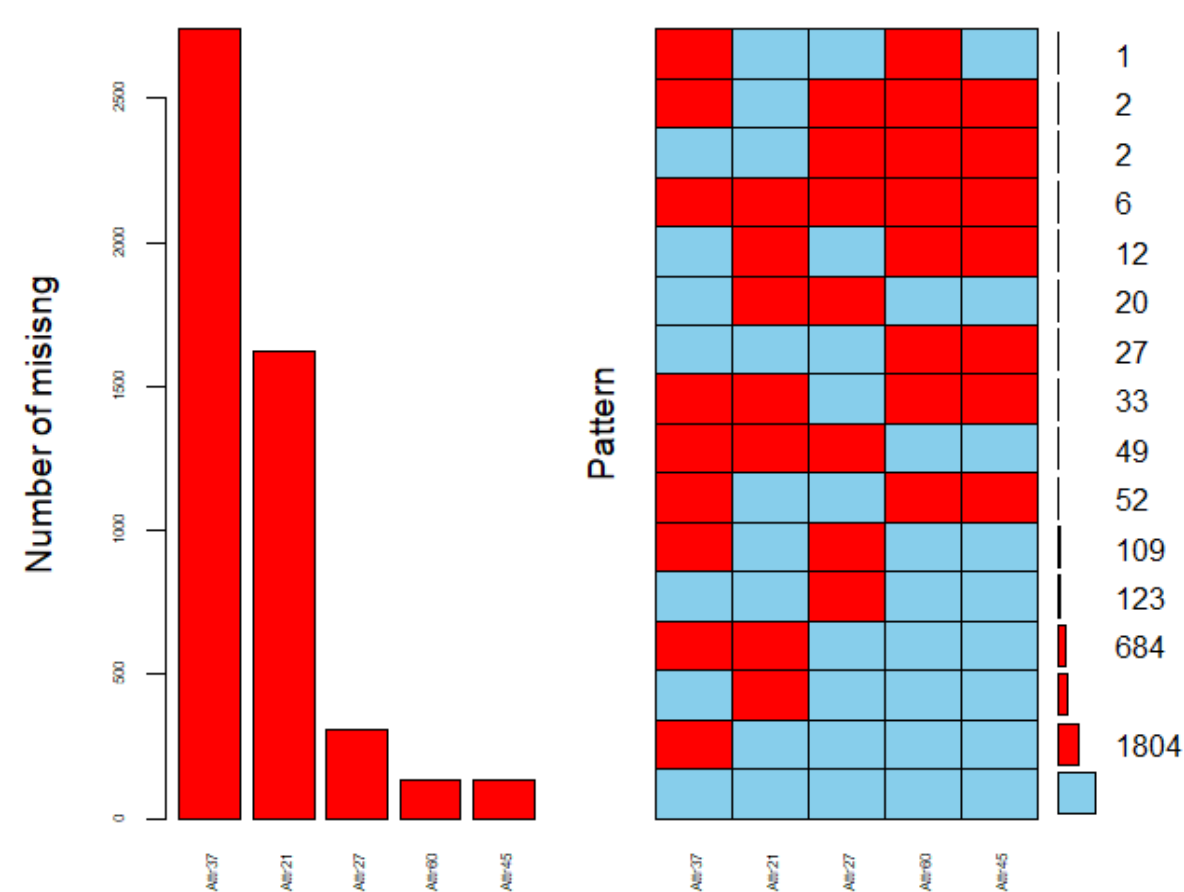
³ Kiesielińska, J., Waszkowski A., *Polish models to predict bankruptcy and its verification*, Ekonomika I organizacja gospodarki żywnościowej 82, 2010, Wydawnictwo SGGW, pages 17-31

SECTION I – Preparing the dataset

Data which we used comes from a polish bankruptcies dataset on UCI Machine Learning Repository.⁴ Firstly we analyzed data for 1st year of forecasting period and therefore defaults mean that company default 5 years from that point. All of the basic 64 variables⁵ are transformed accounting data and various financial indicators (e.g. RoA, RoE, etc.). There were initially 7027 observations including 271 defaults which make for ~3.5% of the dataset.

Firstly we analyzed how many missing data are there in the set. Some variables were more prone to have NA's but overall 3833 observations were not complete (including at least one missing variable). Number of missing for 5 most uncomplete variables are seen on the Figure 1.

Figure 1 - Variables with the most missing data



Source: Own elaboration using R 3.5.1

⁴ Accessible on: <https://archive.ics.uci.edu/ml/datasets/Polish+companies+bankruptcy+data>

⁵ Full list with descriptions available in Appendix 2

Wanting to retain most possible information while removing variables with unacceptable ratio of missing data, we introduced 5 factor variables indicating that there were missing data:

Attr65 – no long term liabilities (omit Attr37)

Attr66 – no financial expenses (omit Attr27)

Attr67 – no inventory (omit Attr60 & 45)

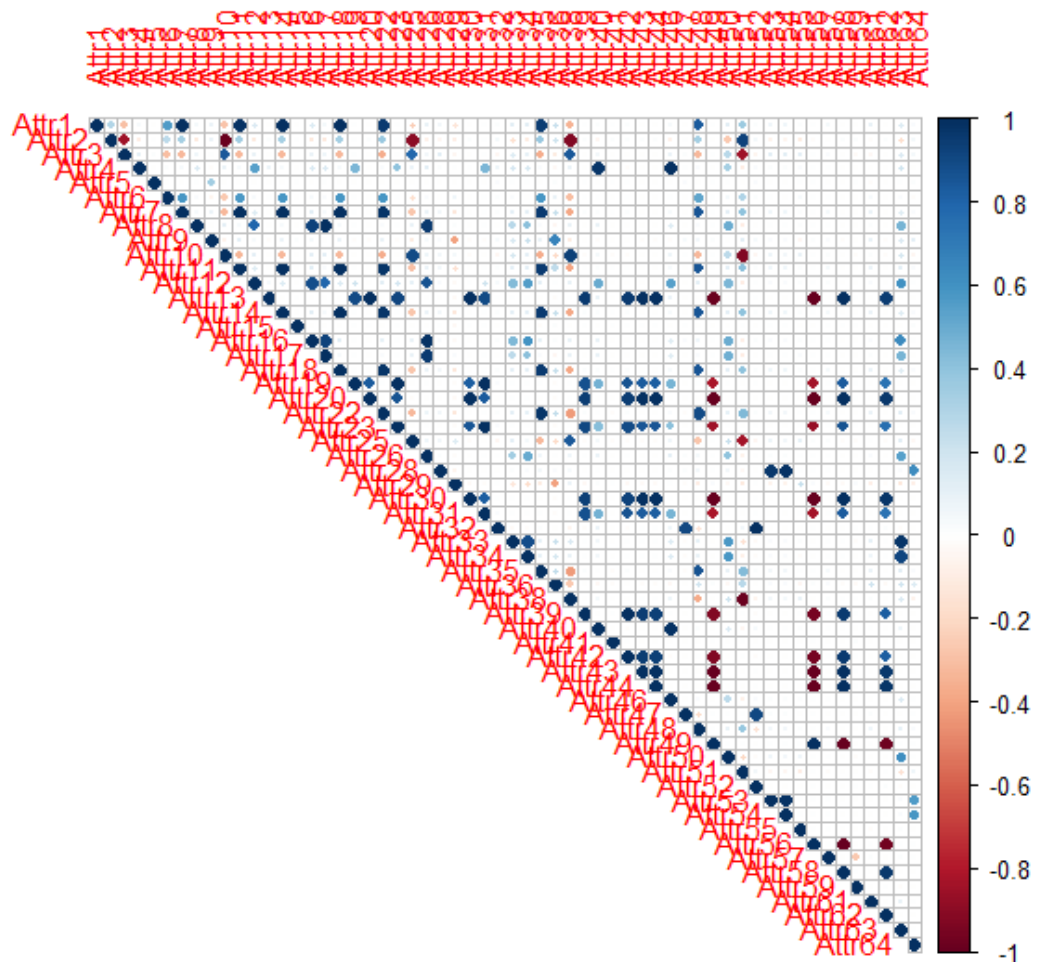
Attr68 – no extraordinary items (omit Attr11)

Attr69 – no receivables (omit Attr61)

Subsequently we omitted columns with over 3% missing observations from further analysis. Since most of the missing came from the same observations we removed all of the (around 200 observations). Having in mind that retaining as much defaults as possible is crucial we find out that there are still around 3.5% of defaults. For some of the observations for which we already had the factor variable we decided to replace NA with median from the dataset (because they were single cases).

Next we analyzed correlation between variables. Correlation matrix can be seen on Figure 2.

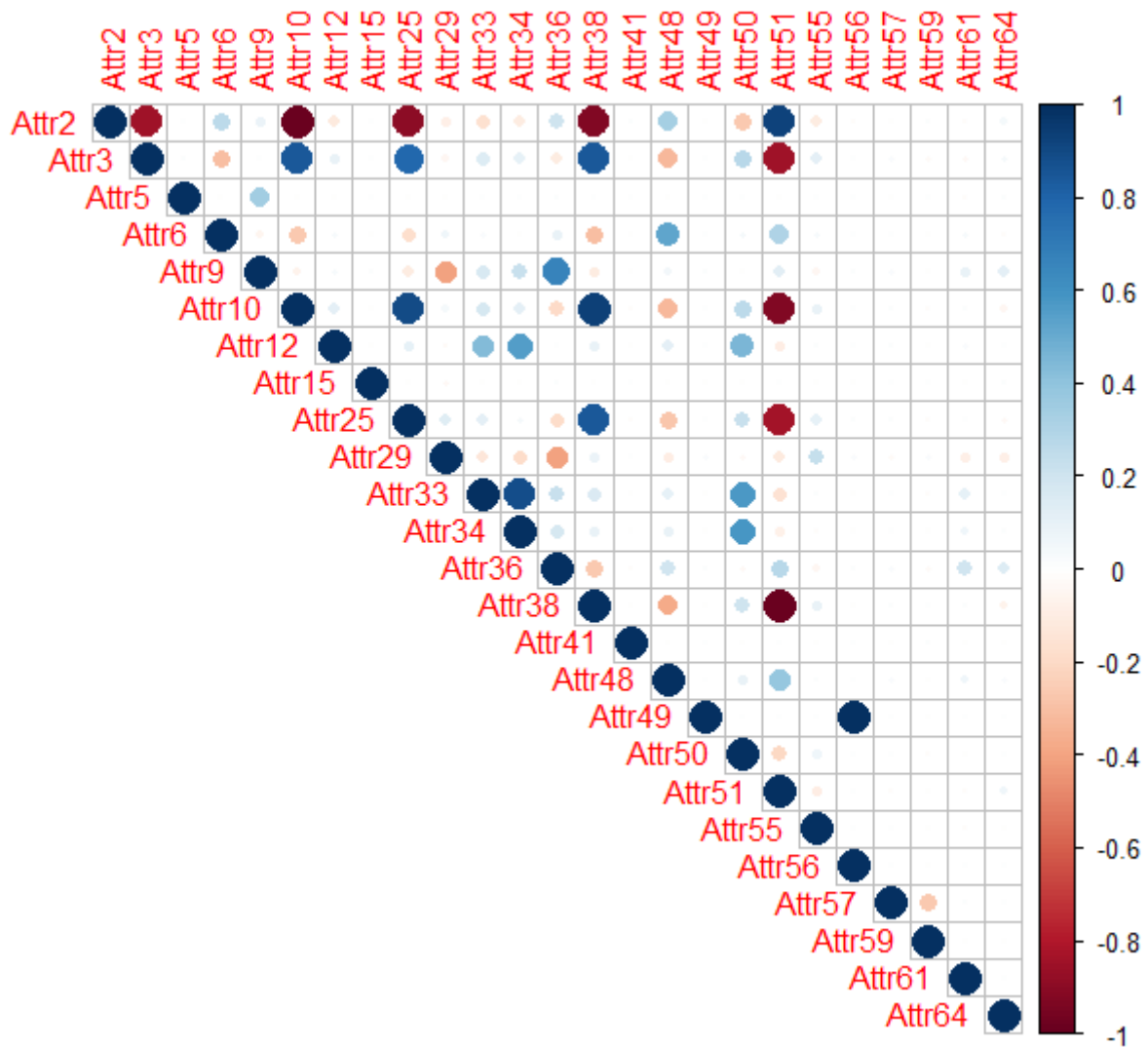
Figure 2 - Correlation matrix for variables before removals



Source: Own elaboration using R 3.5.1

It can be seen that there are a lot of highly correlated variables. We filtered all the variables that are correlated with at least 2 other with correlation higher than 90% . Unfortunately it resulted in half of the variables being gone. Fortunately though it meant that there were almost no high correlated data and no missing observations at all. Correlation matrix for the cleaned data can be seen on Figure 3.

Figure 3 - Correlation matrix after removals



Source: Own elaboration using R 3.5.1

Correlations look much better, although some of them are still high. As we will be trying to retain as much variables as possible we will add those correlated variables as interactions when building model.

Further problem lies in the distribution of variables – there are A LOT of outliers in the data. With first estimations combined problems of high correlation and very high variance of most of the variables resulted in complete separation and Hauck Donner effect – instability of estimation in logisitc regression. To confront that problem we decided to replace some of the outliers with other values:

$values > 4.5 * IQR \rightarrow remove\ value$

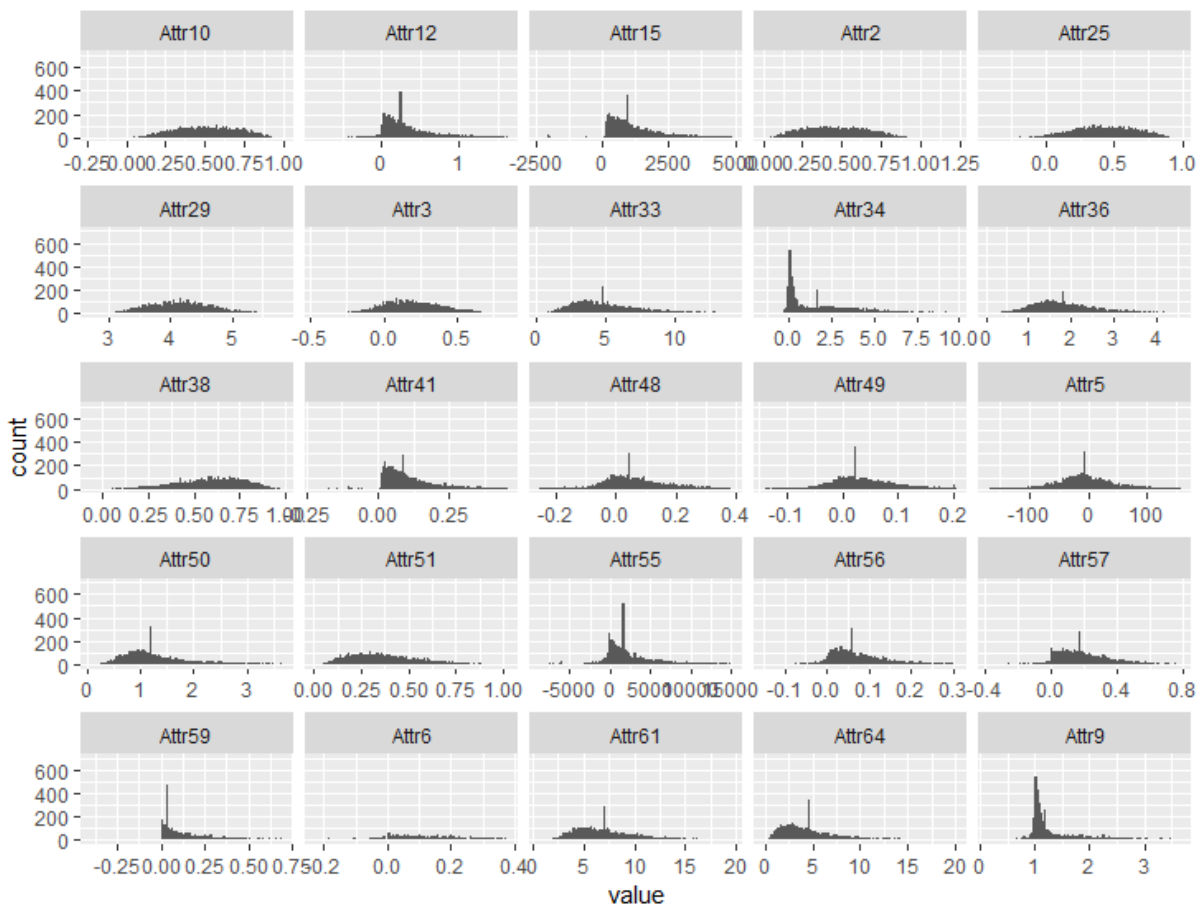
$3 * IQR < values \leq 4.5 * IQR \rightarrow replace\ with\ 95th\ quantile\ value$

$1.5 * IQR < values \leq 3 * IQR \rightarrow replace\ with\ median$

where: IQR – interquartile range

Therefore we are left with 4254 observations, while still retaining same percentage of defaults in dataset. On Figure 4 histograms of all (beside factor) variables (in Attr59 and Attr6 there are missing bins for zeros as they were larger than the scale – we shall emphasize on it below) are shown.

Figure 4 - Histograms for all variables



Source: Own elaboration using R 3.5.1

We can see that data is far from normally distributed and there are still values on the edges of distribution graph, but the improvement is undeniable. Also as mentioned below, Attr6 and Attr59 both have around 45% of zeros within its values but we decided to keep them in further analysis – maybe those with positive value of retained earnings/long-term liabilities are more prone to default.

Next step in our analysis is to transform some variables. After computing Information Values (IV) for all of the remaining variables, we decided that Attr12 should be binned as its suspiciously high predictive power (of 0.9) would work better when binned into two groups with borderline value of 0.06 which splits variable into groups with default rates of 14% and 2% respectively.

We also added interactions between correlated variables, interactions that would give us nominal values of accounting measures and some transformations to variables which had very high IQR (*such as logarithmic transformation adjusted for negative values – $\log(x + 1)$*).

SECTION II - Estimating models

With cleaned and prepared dataset with almost the same percentage of defaults as initial dataset we started estimating first, basic logarithmic regression model. At first we split our dataset into training and testing sets with a 70/30 proportion retaining default percentage in both subgroups. All of the models were validated using repeated k-fold cross validation for estimation of forecasts with 5 folds and 5 repeats.

First model was estimated on all variables with interactions. A lot of variables were statistically insignificant and so the AIC (Akaike's Information Criterion) was 514.74. We set the cut-off point on 0.02, just to be sure that we are identifying as much bankrupts as we can. Its' accuracy on test data was 79.76% but sensitivity (which in predicting bankruptcies should be our main goal) was only 83.72%. Estimated forecast sensitivity and specificity were 75.6% and 79.3% respectively.

Second model was estimated using same variables but we applied forward and back propagation (simultaneously doing general-to-specific and specific-to-general methods) minimizing AIC as our priority (if removing certain variable improves AIC – remove it). We were left with 20 variables, although not all of them statistically significant at p-value = 0.05. AIC was 485.58 and estimated forecasts were looking much better than in the first model (Sens. = 82.4% and Spec. = 76.7%), however accuracy of the model and its' sensitivity on test data did not improve – area under ROC curve and accuracy fell down.

At last we tried removing all those interactions and estimating model on only cleaned and prepared variables without interactions and transformed variables using AIC “both-side propagation” mentioned in second model. That way we obtained third model with AIC = 500.91 – worse than in second model. Estimated accuracy was similar to the second model but its' area under ROC on test data for cut-off point of 0.02 improved to 91.78% and, more importantly, sensitivity increased to 86.05%.

Comparison of the models' coefficients estimations can be seen in the Appendix 1. Comparison of the models' accuracy is presented in Table 1 – AUC means area under curve. Underlined are the best values in each metric. Despite not being the most accurate overall we chose Model 3 as the best one because of the highest sensitivity and simpler form with less variables.

Table 1 - Comparison of models' performance on test data

	AIC	Accuracy	Sensitivity	Specificity	AUC
Model 1	514.74	<u>79.76%</u>	83.72%	<u>79.63%</u>	91.00%
Model 2	<u>485.58</u>	78.04%	83.72%	77.84%	90.77%
Model 3	500.91	75.14%	<u>86.05%</u>	74.76%	<u>91.78%</u>
<u>Model 3.1</u>	642.83	65.73%	86.04%	65.02%	87.93%

Source: Own elaboration using R 3.5.1

Considering Model 3 as our best model, we decided to remove all the statistically insignificant variables ($p - value > 0.05$) so the odds ratios and marginal effects would be interpretable and significant – resulting in Model 3.1.

In Model 3.1 we were left with only 9 variables but the drop in accuracy was visible. In case of interpretability we decided that because sensitivity estimations and sensitivity on test data did not differ much between Model 3 and 3.1 to chose Model 3.1 as our final estimation. We then conducted the Hosmer and Lemeshow (H-L) GoF (Goodness of Fit) test to determine whether our model fits the data well. As we eliminated overfitting from our analysis (because estimated forecasts were similar to the ones obtained on test data) we overcame main flaw of the H-L test. P-value of the test = 0.29 indicates that there is indeed good fit and event rates among 10 groups match expected rates.

In Table 2 we present determinants along with their odds ratio – impact on the odds of bankruptcy. *Odds ratio value* < 1 means that for one unit increase of a variable the odds of defaulting are $1/\text{odds ratio}$ times lower. For *value* > 1 we know that odds of defaulting increase by *value* (or by $(\text{value} - 1) * 100\%$). For *value* = 1 we know that that variable does not have an impact on odds of going bankrupt.

Table 2 - Odds ratios and descriptions of variables in Model 3.1

Variable	Description	Odds ratio
Attr6	$\frac{\text{retained earnings}}{\text{total assets}}$	0.003
Attr12	$\frac{\text{gross profit}}{\text{short – term liabilities}}$	0.323
Attr33	$\frac{\text{operating expenses}}{\text{short – term liabilities}}$	1.136
Attr38	$\frac{\text{constant capital}}{\text{total assets}}$	0.032
Attr49	$\frac{\text{EBITDA}}{\text{sales}}$	991.234
Attr57	$\frac{(\text{curr. assets} - \text{inventory} - \text{short – term liabilities})}{(\text{sales} - \text{gross profit} - \text{depreciation})}$	0.223
Attr651	no long – term liabilities	0.073
Attr661	no financial expenses	75.527

Source: Own elaboration using R 3.5.1

It can be seen that only Attr33, Attr49 and Attr66 impact odds of bankruptcy positively (increase odds of bankrupting) – despite the level of the magnitude which is not interpretable due to specificity of the dataset. It is also seen in the Table 3 where marginal effects for Model 3.1 are provided.

Table 3 - Marginal effects for Model 3.1

Variable	AME	SE	z	p	lower	upper
Attr12	-0.0278	0.0124	-2.2390	0.0252	-0.0522	-0.0035
Attr33	0.0031	0.0012	2.5172	0.0118	0.0007	0.0056
Attr38	-0.0844	0.0191	-4.4117	0.0000	-0.1219	-0.0469
Attr49	0.1698	0.0641	2.6481	0.0081	0.0441	0.2955
Attr57	-0.0369	0.0194	-1.9068	0.0565	-0.0749	0.0010
Attr6	-0.1410	0.0386	-3.6535	0.0003	-0.2167	-0.0654
Attr651	-0.0144	0.0058	-2.4864	0.0129	-0.0257	-0.0030
Attr661	0.4827	0.0520	9.2809	0.0000	0.3808	0.5847

Source: Own elaboration using R 3.5.1

AME columns gives us information on how, with unchanged other values, change of that particular variable would influence the bankruptcy probability. Therefore it is visible, that not having any financial expenses increases probability of default by $1 * 0.4827 * 100 = 48.27$ percentage points. On the other hand, increase of *retained earnings / total assets* ratio by 0.1 would decrease probability of default by 1.41 percentage points. All (but Attr57) variables are statistically significant, therefore interpretable.

However, that set of significant variables in Model 3.1 is slightly different than in literature⁶ on bankruptcy prediction among polish companies as there is no sign of financial indicators such as RoA, WCR or RoE (*Return on Assets, Working Capital Ratio and Return on Equity*). One element of financial statement is reoccurring in both literature and our model – short-term liabilities. It might be that those models were estimated using data for 1 year prior and our model is estimated 5 years prior to bankruptcy so there lies the difference.

⁶ Ptak-Chmielewska A.: *Prediction models of SME bankruptcy in Poland – analysis using Cox survival model and logistic regression model*. *Ekonometria* 4 (46), 2014, s. 9-21

SECTION III – Comparison of models

We were curious if this difference is reproducible and would be the same in our analysis – therefore we conducted second estimation on data 1 year prior to the bankruptcy. That dataset consisted of 5910 observations with 410 defaults and was from the same repository as the previous one.

Having in mind that the paper should not be too long and readable, we omitted data preparation and feature selection description – we followed similar approach as with the first dataset so we will just show the model estimation and the results for comparison.

Model 4, which was estimated on the data 1 year prior to bankruptcy using general-to-specific approach appeared to have less accuracy with cutoff point set at 0.02, so in this case we decided to set it at 0.03. Estimated forecasts, which we obtained using once again repeated k-fold cross validation with 5 repeats and 5 folds, showed Sensitivity = 86.56% and AUC = 85.86%. Thankfully, forecast on test data gave similar results: Sensitivity of 85.53% and AUC = 85.24% - means no overfitting. Next, we computed marginal effects for that model as they are both easier interpreted and more comparable than odds ratio. In Table 4 there are compared main determinants and their marginal effects between models 3.1 (5 years prior to bankruptcy) and 4 (1 year prior).

Table 4 - Marginal effects for Model 4

Variable	AME	SE	z	p	lower	upper
Attr13	-0.1782	0.0616	-2.8933	0.0038	-0.2990	-0.0575
Attr29	-0.0250	0.0052	-4.8121	0.0000	-0.0352	-0.0148
Attr3	-0.0602	0.0163	-3.6872	0.0002	-0.0922	-0.0282
Attr30	0.0544	0.0248	2.1947	0.0282	0.0058	0.1031
Attr32	0.0035	0.0009	3.9106	0.0001	0.0017	0.0053
Attr39	-0.1762	0.0776	-2.2702	0.0232	-0.3283	-0.0241
Attr41	-0.1393	0.0303	-4.6032	0.0000	-0.1987	-0.0800
Attr44	-0.0005	0.0001	-3.7862	0.0002	-0.0008	-0.0003
Attr52	-1.4239	0.3339	-4.2639	0.0000	-2.0784	-0.7694
Attr62	0.0006	0.0002	3.6088	0.0003	0.0003	0.0009
Attr661	0.2308	0.0331	6.9754	0.0000	0.1659	0.2956

Source: Own elaboration using R 3.5.1

As we can see, only Attr66, so factorial indicator of absence of financial expenses is present in both models – that proves our suspicions that determinants of default on firm market differ between periods prior to bankruptcy. We can also see that some of the variables are indeed overlapping with those occurring in mentioned literature. For example Attr3, which formula is *working capital / total assets*, have negative impact on bankruptcy probability – same as in few of the polish discriminant analysis models.⁷ Attr13, *gross profit / sales*, was also present in Gruszczyński's⁸ best performing logit model – also with negative value on bankruptcy. However some of the most impactful variables from literature models, such as debt ratio (*total liabilities / total assets*) appeared to be completely useless in both of our models. It might be the specificity of the data – our datasets included no more than 6% of defaults within the dataset while almost all literature models were estimated on balanced, far less numerous dataset.

⁷ Kiesielińska, J., Waszkowski A., *Polish models to predict bankruptcy and its verification*, *Ekonomika I organizacja gospodarki żywnościowej* 82, 2010, Wydawnictwo SGGW, pages 22-25

⁸ Kiesielińska, J., Waszkowski A., *Polish models to predict bankruptcy and its verification*, *Ekonomika I organizacja gospodarki żywnościowej* 82, 2010, Wydawnictwo SGGW, pages 25-27

CONCLUSION

Our main hypothesis was whether it is possible to build models 5 years and 1 year prior to bankruptcy that would work as a tool of early warning. In analysis conducted above we succeeded in estimating such models that proved to be fairly accurate on very unbalanced dataset for both of the analyzed periods. We acknowledge that literature models are said to be far more accurate, nevertheless we know that they were built on significantly smaller samples using 1:1 (defaults: non-defaults) balanced data and so we consider these models as theoretical rather than really applicable ones. Therefore we conclude that it is possible to estimate quite accurate logistic regression model that could be useful to certain “players” on the market.

Our second hypothesis was if the models are accurate, how do the determinants differ between two estimated periods. In the last section we showed that impactful variables differ majorly between two forecasting periods, however we came to the conclusion that some of the financial indicators used in the model forecasting 1 year ahead overlapped with those from literature – therefore further justifying our choice of variables.

Bankruptcies are inevitable but it is better to know when and where they might occur – we proved that there might be fairly well working solutions even for such specific and rapidly changing market as Polish.

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APPENDICES

Appendix 1 - Table of coefficients for Models 1, 2, 3, 3.1

Results				
	<i>Dependent variable:</i> class			
	Model 1	Model 2	Model 3	Model 3.1
Attr2	13.747 (12.023)	16.449*** (6.130)	5.252** (2.196)	
Attr3	6.280 (13.339)		-1.931* (1.064)	
Attr5	0.002 (0.005)			
Attr6	-3.443 (2.248)	-4.405** (1.891)	-3.458* (1.877)	-5.730*** (1.505)
Attr9	0.614 (0.436)		0.386* (0.211)	
Attr10	3.439 (2.882)	5.208** (2.378)	4.008* (2.358)	
Attr12			-1.384** (0.668)	-1.131** (0.502)
Attr15	0.0003* (0.0001)	0.0003** (0.0001)	0.0002* (0.0001)	
Attr25	-2.468 (3.628)			
Attr29	0.542 (1.032)			
Attr33	0.233** (0.102)	0.174** (0.068)	0.095 (0.065)	0.127** (0.050)
Attr34	0.124 (0.110)			
Attr36	-0.582 (0.363)			
Attr38	-6.445** (2.787)	-6.460*** (2.096)	-7.035*** (2.059)	-3.429*** (0.737)
Attr41	0.399 (1.869)			
Attr48	1.501 (2.534)			
Attr49	0.523 (5.439)		13.182*** (3.251)	6.899*** (2.565)
Attr50	0.588 (0.498)	0.805* (0.444)	0.734* (0.396)	
Attr51	10.517 (8.720)		-4.909*** (1.823)	

Attr55	-0.001*	-0.001		
	(0.001)	(0.001)		
Attr56	-9.862***	-7.761***	-6.295**	
	(2.996)	(2.590)	(2.464)	
Attr57	-2.839**	-2.925***	-3.180***	-1.500*
	(1.173)	(0.938)	(1.066)	(0.780)
Attr59	0.504			
	(0.980)			
Attr61	0.017			
	(0.160)			
Attr64	-0.175	-0.067		
	(0.153)	(0.050)		
Attr651	-1.536***	-1.292***	-0.851**	-2.623***
	(0.452)	(0.385)	(0.349)	(0.400)
Attr661	13.491**	6.052**	5.740***	4.324***
	(4.376)	(0.429)	(0.393)	(0.303)
Attr671	0.647			
	(0.990)			
Attr681	22.791	21.413	22.145	
	(678.988)	(728.862)	(670.732)	
Attr12_BINNED	0.350			
	(0.405)			
I(Attr22)	0.512	-6.331		
	(8.316)	(4.367)		
I(Attr253)	9.247**	9.285**		
	(4.513)	(3.656)		
I(log1p(Attr61))	-0.437			
	(1.421)			
I(log1p(Attr64))	0.848			
	(1.308)			
Attr2:Attr29	-0.326			
	(1.372)			
Attr661:Attr12_BIN NED	0.579			
	(0.875)			
Attr38:Attr661	-6.905			
	(4.407)			
Attr9:I(exp(Attr29))	-0.001			
	(0.004)			
Attr2:Attr51	-17.778*	-5.018**		
	(10.777)	(2.240)		
Attr2:Attr661	-6.253			
	(4.023)			
Attr2:Attr3	-4.578			
	(13.802)			
Attr3:Attr10	11.018	14.307**		
	(13.591)	(7.275)		
Attr3:Attr25	-4.844			
	(5.074)			

Attr3:Attr38	-13.151 (9.531)	-13.189** (6.593)		
Attr25:Attr38	0.253 (7.983)	-6.054** (2.660)		
Attr49:Attr56	93.948*** (26.153)	93.214*** (19.227)		
Attr29:Attr55	0.0002* (0.0001)	0.0002 (0.0001)		
Constant	-12.625* (6.861)	-9.171*** (3.282)	-3.952* (2.311)	
Observations	2,979	2,979	2,979	2,979
Log Likelihood	-210.369	-219.791	-232.456	-312.042
Akaike Inf. Crit.	514.738	485.583	500.912	642.083

Note: *p<0.1; **p<0.05; ***p<0.01

Source: Own elaboration using R 3.5.1

Appendix 2 - Variables descriptions

Variable	Description
Attr1	net profit / total assets
Attr2	total liabilities / total assets
Attr3	working capital / total assets
Attr4	current assets / short-term liabilities
Attr5	[(cash + short-term securities + receivables - short-term liabilities) / (operating expenses - depreciation)] * 365
Attr6	retained earnings / total assets
Attr7	EBIT / total assets
Attr8	book value of equity / total liabilities
Attr9	sales / total assets
Attr10	equity / total assets
Attr11	(gross profit + extraordinary items + financial expenses) / total assets
Attr12	gross profit / short-term liabilities
Attr13	(gross profit + depreciation) / sales
Attr14	(gross profit + interest) / total assets
Attr15	(total liabilities * 365) / (gross profit + depreciation)
Attr16	(gross profit + depreciation) / total liabilities
Attr17	total assets / total liabilities
Attr18	gross profit / total assets
Attr19	gross profit / sales
Attr20	(inventory * 365) / sales
Attr21	sales (n) / sales (n-1)
Attr22	profit on operating activities / total assets
Attr23	net profit / sales
Attr24	gross profit (in 3 years) / total assets
Attr25	(equity - share capital) / total assets
Attr26	(net profit + depreciation) / total liabilities
Attr27	profit on operating activities / financial expenses

Attr28	working capital / fixed assets
Attr29	logarithm of total assets
Attr30	(total liabilities - cash) / sales
Attr31	(gross profit + interest) / sales
Attr32	(current liabilities * 365) / cost of products sold
Attr33	operating expenses / short-term liabilities
Attr34	operating expenses / total liabilities
Attr35	profit on sales / total assets
Attr36	total sales / total assets
Attr37	(current assets - inventories) / long-term liabilities
Attr38	constant capital / total assets
Attr39	profit on sales / sales
Attr40	(current assets - inventory - receivables) / short-term liabilities
Attr41	total liabilities / ((profit on operating activities + depreciation) * (12/365))
Attr42	profit on operating activities / sales
Attr43	rotation receivables + inventory turnover in days
Attr44	(receivables * 365) / sales
Attr45	net profit / inventory
Attr46	(current assets - inventory) / short-term liabilities
Attr47	(inventory * 365) / cost of products sold
Attr48	EBITDA (profit on operating activities - depreciation) / total assets
Attr49	EBITDA (profit on operating activities - depreciation) / sales
Attr50	current assets / total liabilities
Attr51	short-term liabilities / total assets
Attr52	(short-term liabilities * 365) / cost of products sold
Attr53	equity / fixed assets
Attr54	constant capital / fixed assets
Attr55	working capital
Attr56	(sales - cost of products sold) / sales
Attr57	(current assets - inventory - short-term liabilities) / (sales - gross profit - depreciation)
Attr58	total costs / total sales
Attr59	long-term liabilities / equity
Attr60	sales / inventory
Attr61	sales / receivables
Attr62	(short-term liabilities * 365) / sales
Attr63	sales / short-term liabilities
Attr64	sales / fixed assets

Source: <https://archive.ics.uci.edu/ml/datasets/Polish+companies+bankruptcy+data>