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An early-warning indicators' framework for Polish banking sector

1. Introduction

Early warning indicators (EWIs) are substantial tool of analysis used in micro- and macroprudential policymaking. Signalling with substantial lead symptoms of an incoming financial crisis they provide financial supervisors with appropriate timespan needed to effectively apply supervisory instruments allowing to diminishing negative impact of the distress on financial institutions. To appropriately fulfil their role EWIs should signal instabilities in their early stage of development (at least two quarters ahead), discriminate clearly future crisis from non-crisis periods (optimal balance between false positive and true positive rate), capture characteristics of a local economy and its financial system, be based on easily interpretable indicators and selected with formal procedure that allows to justify their application to public opinion.

In this paper we present a formal framework that allows to search through a group of candidate time series dataset and find the EWIs that reflect mentioned before advantages and are applicable for the Polish banking sector. Our approach is based on two stages. In the first step logistic regression model is applied to microprudential data gathered for 20 Polish biggest banks to estimate probabilities of default (PDs) of the biggest banks operating in Poland. The input individual banks database consists of capital adequacy, credit risk sensitivity and concentration, market risk and profitability time series (available for years 2007–2018). In the second stage computed banks' PDs are used to construct individual banks' stability indicators applied finally to select most statistically significant EWIs from the group of candidate macroprudential macro, financial sector, interconnectedness and property prices indicators with panel regression model. The quality of proposed EWIs are then compared

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with Area Under the Receiver Operating Characteristics (AUROC) Curve metrics and confronted with commonly used in the literature (total) credit-to-GDP gap measure to find that the best-performing ones are: bank credit-to-GDP gap, reflecting financial cycle and spread of the 10Y government bonds over the WIBOR 3M, emanating interest rate and liquidity risk. According to the knowledge of the author it is the first survey that provides for the Polish banking sector consistent analytical structure that combines microprudential stability indicators approach with selection of the macroprudential EWIs using panel regression model.

The article is organized as follow. The second section explores literature about EWIs and potential causes of a financial crisis. Next section is devoted to micro and macroprudential dataset description. Then the two-stages framework used for EWIs selection is described. Last two parts present and discuss gained results and derive conclusions for practical applications.

2. Literature review

The first simple early warning indicators were applied in 1970' to analyze currency crashes[2]. Fast development of early warning measures can be dated back to 1990' when Kaminsky and Reinhard[3] and Frankel and Rose[4] proposed formal methodologies for analyzing twin banking-balance of payments and currency crises. First EWIs were based on univariate methods which allowed to transform single time series into indicator that was supposed to signal crisis[5]. More recent surveys introduce multivariate models[6] to compile EWIs. The popular method of crisis leading indicator construction was using multinomial

[2] J.F.O. Bilson, *Leading indicators of currency devaluations*, "Columbia Journal of World Business" 1979, vol. 14, pp. 62–76.

[3] G.L. Kaminsky, C.M. Reinhart, *The twin crises: The causes of banking and balance of payments problems*, Board of Governors of the Federal Reserve System, International Finance Discussion Papers no. 544, 1996.

[4] J.A. Frankel, A.K. Rose, *Currency crashes in emerging markets: An empirical treatment*, "Journal of International Economics" 1996, vol. 41 (3–4), pp. 351–366.

[5] G.L. Kaminsky, S. Lizondo, C.M. Reinhart, *Leading indicators of currency crises*, "IMF Staff Paper" 1998, vol. 45, no. 1, pp. 1–48.

[6] J.A.G. Frankel, G. Saravelos, *Are leading indicators of financial crisis useful for assessing country vulnerability? Evidence from the 2008–09 global crisis*, NBER Working Paper no. 16047, 2010; A.K. Rose, M.M. Spiegel, *Cross-country causes and consequences of the 2008 crisis: Early warning*, NBER Working Paper no. 15357, 2009.

probit or logit models or factor methods. The two main EWIs selection procedures were used: minimizing signal-to-noise ratio or decision-makers loss function[7].

The recent research on EWI is aimed at applying new estimation techniques, exploring new datasets and improving quality of constructed measures. Simple binary probit/logit models were replaced with multivariate versions generalizing their output to broader spectrum of possible states: "normal" times, crisis, post-crisis, etc[8]. Moreover, discrete choice indicators were replaced with continuous measures[9]. The continuous approach allowed to forecast full spectrum of crisis costs. Beside that non-linear models like Markov-switching frameworks were used to catch changing nature of the (hidden) forces driving characteristics of input time series[10]. Other interesting augmentations include banking sector systemic risk spillovers' analysis with application of bans' interlinkages data[11]. Some researchers tried also to consider preselection of policymaker's preferences on missed crisis and false alarms[12]. Other proposed use individual banks' data and panel estimation models to select optimal banking sector EWIs[13]. This paper follows the last approach trying to adopt the methodologies to local data accessibility and characteristics of the Polish banking sector.

3. Data

In this section we describe the dataset used in the research. Our main goal of this survey phase was to find set of variables that capture local characteristics of Polish economy and banking sector. However as the financial markets are generally more and more interconnected and Polish banking sector opens more and more widely to the rest of the world, we tried to find also measures

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7 M. Bussiere, M. Fratzscher, *Towards a new early warning system of financial crises*, "Journal of International Money and Finance" 2006, vol. 25, pp. 953–973.

8 Ibidem.

9 J.A.G. Frankel, G. Saravelos, op.cit.

10 A. Abiad, *Early-warning systems: A survey and a regime-switching approach*, IMF Working Paper no. 03/32, 2003.

11 H. Elsinger, A. Lehar, M. Summer, *Using market information for banking system risk assessment*, "International Journal of Central Banking" 2006, vol. 2(1), pp. 137–165.

12 L. Alessi, C. Detken, *Quasi real time early warning indicators for costly asset price boom/bust cycles. A role for global liquidity*, "European Journal of Political Economy" 2011, vol. 27(3), pp. 520–533.

13 N. Jahn, T. Kick, *Early warning indicators for the German banking system: a macroprudential analysis*, Deutsche Bundesbank Discussion Paper no. 27/2012.

that can quantify impact of the potential negative spillover effects coming from external sources.

The database of candidate EWI indicators was divided into 5 time series domains: microprudential, macro, financial sector, interconnectedness data and property prices data. It consisted mainly of Polish data, however in the case of interconnectedness measure we used data from international financial markets. The timespan of the data embraced the last 12 years: from 2007 to 2018 and was limited due to data availability. Below we describe in detail datasets used in the model estimation.

3.1. Macro and macroprudential data

The potential EWI were grouped in four domains: macro, financial sector, interconnectedness and property prices data. They are presented in the Table 1.

Table 1. Potential early waring indicators used in the survey

Type	Variable	Code	Source
Macro	Purchasing managers' index	MA_PMI	Markit Group/Institute for Supply Management of financial activity
	Gross capital formation indicator	MA_GCFI	Polish Central Statistical Office
Financial sector	Total credit-to-GDP gap	FS_TCGDPG	National Bank of Poland
	Bank credit-to-GDP gap	FS_BCGDPG	National Bank of Poland
	10Y treasury constant maturity 3M WIBOR spread	FS_10YTM3MWIBOR	ACI Poland, GPW Benchmark SA, National Bank of Poland
	M3 to GDP ratio	FS_M3GDPR	National Bank of Poland
Inter-connect.	VIX index	I_VIX	Bloomberg
Property prices	Nominal residential property prices	PP_NRPP	Bank for International Settlements, National Bank of Poland
	Real residential property prices	PP_RRPP	Bank for International Settlements, National Bank of Poland
	Nominal commercial property prices	PP_NCPP	Bank for International Settlements, National Bank of Poland
	Ratio nominal residential property prices to nominal income	PP_RNRPPNI	Bank for International Settlements, National Bank of Poland

Type	Variable	Code	Source
	Ratio of nominal residential property price to nominal rent	PP_RNRPPNR	Bank for International Settlements, National Bank of Poland

Source: own elaboration.

3.2. Microprudential data

The micrprudential data used in the survey was classified to 4 main buckets: capital adequacy, credit risk sensitivity, market risk sensitivity and profitability. We included in our analysis the series gathered in the Table 2.

Table 2. Microprudential data used in the survey

Category	Capital adequacy	Credit risk sensitivity/ concentration	Market risk sensitivity	Profitability
Variables	• Tier 1 capital ratio (MI_TIER1) • Total bank reserves to assets ratio (MI_TBRTAR)	• Customer loans to total assets ratio (MI_CLTTAR) • Loan loss provisions • to total loans ratio (MI_LLPTLR) • Large credit expositions to total credit ratio (MI_LCETCR) • Nonperforming loans to total loans ratio (MI_NLTLR)	• Net results from transactions with foreign currencies to income ratio (MI_NRTFCIR) • Net results from transactions with derivatives to income ratio (MI_NRTDIR) • Stocks to total assets ratio (MI_STAR)	• Cost to income ratio (MI_CIR) • EBIT to equity capital ratio (MI_EBITCR) • RoE (MI_ROE) • Share of fee income (MI_SFI)

Source: own elaboration.

4. EWIs framework

4.1. General EWIs framework description

An early warning indicators' construction of can be perceived as the sequential process, that can be divided into three crucial phases 1) framework initialization, 2) model building, estimation and evaluation, 3) interpretation of gained results.

The first phase in concentrated on setting models aims and objectives, making assumptions and data transformation, the second phase deals sequentially with models specification, their estimation and validation, the last one is concentrated on working-out proper understanding of the gained results and its communication to decision-makers and to general public.

4.2. General EWIs framework description

First we introduce bank rating model what is used to estimate probability of default of each individual bank analyzed in the survey $P(y_{i,t}=1)$. The performs it with help of logistic function applied to set of lagged bank specific indicators $(BI_{i,t-1})$ and financial variables (F_t). The model belongs to population-averaged logit model:

$$P(y_{i,t}=1)=\frac{e^{\alpha+\beta BI_{i,t-1}+\gamma F_{t-1}}}{1+e^{\alpha+\beta BI_{i,t-1}+\gamma F_{t-1}}} \tag{1}$$

The bank specific variables are selected from microprudential data described in the previous section. On the left-hand side of the equation above we use data set of Polish banks distress events gathered by the author.

4.3. Panel regression model

In the second stage we assume that our individual banks stability indicators (BSI) are generated with an AR (1) process. To identify key factors of future banking sector distress we use panel version of distributed lag $(1,\ p,q)$ model

$$BSI_{i,t}=\alpha BSI_{i,t-1}+\sum_{j=1}^{J}\beta_j X_{j,t-p}+\sum_{k=1}^{K}\beta_{i,k}Y_{i,k,t-q}+\mu_i+\pi_{i,t} \tag{2}$$

$BSI_{i,t}$ is an individual bank (denoted with subscript i) stability indicators at time t, $X_{j,t-p}$ are macroprudential variables that contribute to the model with their most important lag p and $Y_{i.k,t-q}$ denote bank specific variables which dynamics is caught with lag q. They are included to capture the bank-level variation of the BSI over time. The macroprudential variables depicture sector-level risk. The fixed effect is described by μ_i and $\pi_{i,t}$ embodies idiosyncratic error.

4.4. Quality analysis

The quality of the selected EWI's was validated with the area under the receiver operating characteristics (AUROC) curve approach described in detail by Drehmann and Juselius[14]. The AUROC is computed with the assumption that exceeding chosen threshold (denoted TR) the analysed indicator should signal with certain lead the start of financial destabilization period. The prediction can materialize (noted D) or not (noted ND). The possible outcomes for N cases of such analysis (N = D + ND, number of destabilization periods plus number of non-crisis periods) of this simple analysis can be gathered in the Table 3. Known in the literature as a "confusion matrix".

Table 3. Possible outcomes of the quality analysis procedure

	No destabilization	Destabilization
Indicator stays below a threshold (TR) – no signal	TN: true negative	FN: false negative
Indicator stays above a threshold (TR) – signal	FP: false positive	TP: true positive

Source: own elaboration.

False positive rate (FPR) is defined as $\frac{FP}{TN+FP}$, true positive rate (TPR) equals to $\frac{TP}{FN+TP}$. The AUROC curve is the area under the plot of the $TPR = f\left(FPR(TR)\right)$.

5. Results

In this section we discuss results two-stages model estimation. The rating model was computed for the whole bank sample (20 entities) and dataset time-span embraced years 2007–2018. This model uses the logistic regression and uses microprudential individual data to compute probability of default (PD) of an individual bank i in year t. The gained results are presented in the Table 4.

[14] M. Drehmann, M. Juselius, *Evaluating early warning indicators of banking crises: satisfying policy requirements*, "International Journal of Forecasting" 2014, vol. 30(3), pp. 759–780.

Table 4. Regression statistics of PD-s model for analyzed Polish commercial banks

Variables	t-statistics (*** p<0.01, ** p<0.05, * p<0.1)
MI_TIER1	–0.1296*** (–3.913)
MI_TBRTAR	–1.1135*** (–11.378)
MI_CLTTAR	0.0815*** (3.613)
MI_LLPTLR	0.2466** (2.772)
MI_LCETCR	0.6495* (1.816)
MI_NLTLR	0.3621** (2.314)
MI_NRTFCIR	0.0415 (0.283)
MI_NRTDIR	0.0128 (0.131)
MI_STAR	–0.0014*** (–2.842)
MI_CIR	0.0376 (0,089)
MI_EBITCR	–0.0756*** (–10.351)
MI_ROE	–0.1672*** (–12.986)
MI_SFI	0.0197*** (2.914)
Number of institutions	20
Number of observations	12480

Source: own computations

Table 5. Results of a fixed effects panel regression model for Polish commercial banks

Variables	t-statistics (*** p<0.01, ** p<0.05, * p<0.1)				
BSI(–1)	0,381*** (12,317)	0,347*** (11,429)	0,359*** (11,652)	0,346*** (12,431)	0,255*** (12,602)
MA_PMI(–1)	0.081 (0.153)	0.084 (0.118)	0.077 (0.163)	0.093 (0.209)	0.098 (0.126)
MA_GCFI(–2)	0.012 (0.098)	0.018 (0.101)	0.017 (0.105)	0.021 (0.096)	0.019 (0.105)
FS_BCGDPR(–3)	–0.221*** (–4.462)	–0.206*** (–4.169)	–0.207*** (–4.539)	–0.242*** (–4.935)	–0.281*** (–5.011)
FS_10YTM3MWIBOR(–2)	–0,191*** (–2,318)	–0,173*** (–2,434)	–0,177*** (–2,401)	–0,170*** (–2,421)	–0,176*** (–2,524)
FS_M3GDPR(–2)	–0,039 (–0,133)	–0,042 (–0,104)	–0,033 (–0,095)	–0,057 (–0,144)	–0,045 (–0,128)
I_VIX(–3)		–0,181 (–0,319)	–0,149 (–0,247)		–0,143 (–0,233)
PP_NRPP(–1)			–0,021 (–0,104)	–0,015* (–0,227)	–0,051 (–0,103)
PP_RRPP(–1)			–0,013 (–0,061)	–0,029 (–0,063)	–0,033 (–0,054)

Variables	t-statistics (*** p<0.01, ** p<0.05, * p<0.1)				
PP_NCPP(–1)			–0,007 (–0,031)	–0,012 (–0,045)	–0,008 (–0,038)
PP_RNRPPNI(–1)					–0,002 (–0,024)
PP_RNRPPNR(–1)					–0,004 (–0,009)
CV_TBSV(0)	–0,122*** (–3,001)	–0,121*** (–2,994)	–0,120*** (–3,021)	–0,118*** (–3,004)	–0,211*** (–2,983)
Number of institutions	2448	2448	2448	2448	2448
F statistics	112,7	134,3	107,3	134,5	138.1
Within R2	0.272	0,276	0,278	0,284	0,293

Source: own computations.

The standardized PDs of the individual Polish banks are then combined with their stock market indexes (noted on Warsaw Stock Exchange) to compile individual banks stability indexes (BSI) used then as an input for the second stage panel model. The set of explanatory variables used in this framework consisted of macro, property prices, financial markets and interconnectedness time series. Some of them (e.g. macro) are non-stationary. To eliminate biased statistics and to ease interpretability of the results they were logarithmized and transformed to growth rates. As the bank specific control variable we used their total balance sheet value (CV_TBSV).

At the beginning of the estimation only a short list of explanatory variables was used in estimation. Then, step-by-step the rest of the regressors were added. The most appropriate models were chosen based on AIC criterion.

The gathered statistics shows that general explanatory power of the used models is satisfactory as it reaches 27–29%. Moreover, the gained results allow to identify measures that reveal significant explanatory power regardless of the used model specification.

1. Macroeconomic variables: purchasing managers index (MA_PMI) explains on average only 8,5% of the explained variable standard deviation. PMI is treated in the survey as the leading indicator of the country's real economic condition and estimated parameter value suggests limited impact of the real business cycle on the Polish banking sector stability. The second macroeconomic indicator, gross capital formation indicator (MA_GCFI) as well doesn't show significant importance for banking sector situation. According to the author's opinion the situation can be associated with the fact that

Polish enterprises (especially micro, small and medium ones) use banking credit as the source of their investment only to a limited extent.

2. Financial sector variables: bank credit-to-GDP gap (FM_BCGDPG) – the aggressive bank credit action and low bank risk aversion is very often followed with higher probability of the financial institutions insolvency (negative sign of the coefficient in the model), and this regularity was also noticed in the case of some Polish banks. This variable is responsible (on average) for 23% of the explained variable standard deviation. Second financial variable important for the Polish banking sector condition is spread of the 10Y government bonds over the WIBOR 3M (FS_10YTM3MWIBOR). It explains a bit less standard deviation of the explanatory variable, over 17%. The higher short-term interbank rates spread is connected with lack of the confidence in the wholesale money market and problems with bank's short-term solvency. The last financial market variable that captures characteristics of money supply transmission channel, the ratio of M3 to GDP (FM_M3GDPR), seems to be irrelevant for the Polish banking sector condition in the analyzed time perspective.
3. Interconnectedness data: VIX Index was included in the model in different specifications. According to the historical observations higher volatility on the international financial markets can generate negative spillover effects for financial institutions operating in the banking sector of the small open economy. Therefore, the coefficient associated with this explanatory variable is expected to have negative sign. In the case of Poland the character of the relationship between VIX and banking sector stability indicator was in line with predictions. However, regardless of the model version it was statistically insignificant in explaining variation of the banking sector stability indicator. It can be concluded that Polish banking sector is still relatively weakly connected with international financial system. The short and long term Polish commercial banks' liquidity is mainly financed with funds gathered from retail clients, what supports this sector stability.
4. Property prices data: this group of variables was strongly represented in the survey included real and nominal price series observed in residential and commercial real estate market. In many countries (US, group of UE members) the price boom in the real estate market financed with high risk exposed private credit was one of the most important sources of the last financial credit. Significant increase of prices was also observed in Poland in 2007–2010 and in 2018, but due to accumulated delayed demand for residential and commercial real estates it didn't caused serious negative effects for local banking

sector stability. In the estimated model the real estate prices are generally irrelevant for explaining variance of the stability indicator.

The empirical results of the survey allow us to identify sources of Polish banking sector instability and early warning indicators that, when observed, can reveal signals of incoming distress. These sources are heterogenous:

- the clearest and most robust warnings come from bank credit-to-GDP gap series and suggests that Polish banking sector condition is closely connected with credit action cycle,
- the condition of the local banking sector is also connected with money market risk indicator spread of the 10Y government bonds yield over WIBOR 3M that highlights importance of the assets structure and risk management quality in these institutions.

It is however worthy to notice that they are generally limited to the processes taking place within local jurisdiction. In the authors' opinion it can be concluded that Polish banking sector is relatively resistant to international shocks and attention of the macroprudential policy makers should be concentrated on the internal problems of locally operating institutions.

In the last part of the analysis potential EWIs were confronted with reference time series, (total) credit-to-GDP gap. The evaluation procedure was performed with univariate forecasting models that allowed to compute AUROC statistics. The gained results were presented in the Table 6.

Table 6. AUROC statistics for EWIs

Variable	AUROC
FS_BCGDPR	0.81
FS_10YTM3MWIBOR	0.79
FS_TCGDPG	**0.78**
MA_PMI	0.75
PP_NRPP	0.73
MA_GCFI	0.73
PP_RNRPPNI	0.72
I_VIX	0.72
PP_RRPP	0.69
PP_NCPP	0.67
PP_RNRPPNR	0.63

Source: own computations.

According to the AUROC criterion the two time series with statistically significant coefficients in the panel regression model (bank credit-to-GDP gap and spread of 10Y treasury yield over 3M WIBOR) perform slightly better than reference series (total credit-to-GDP gap). The rest of the candidate variables, among them all macroeconomic and property prices indicators, were not so effective in predicting Polish banking sector instability.

6. Conclusions

The Polish banking sector is generally considered as a stable one. However, a subgroup of big local banks is perceived to be less resistant to negative shocks what, in the time of potential next crisis, can generate serious problems for rest of the banking sector. In this research we tried to implement statistical framework that will take into account Polish banks' heterogenous financial conditions and provide macroprudential policy makers with tool allowing to predict their future conditions. We hope that the described results of the analysis can be used as the useful voice in the discussion about which variables should be monitored in the process of Polish banking sector stability evaluation.

We start our survey with construction banking sector stability indicator based on microprudential data. This indicator combines individual institutions probabilities of default and their stock market indexes. We then use this indicator to select with help of panel regression model a group of reliable early warning indicators. According to gained result the best indicators of the future banking sector instability are financial sector time series and business cycle indicators. The two financial sector indicators, bank credit-to-GDP gap and spread of 10Y treasury yield over 3M WIBOR, benchmarked with reference credit-to-GDP gap measure perform according to AUROC statistics slightly better in predicting future financial distress. In the author's opinion it emphasizes the importance of monitoring broader set supervisory variables, namely these describing credit cycle characteristics and short-term liquidity tensions. Simultaneously the gained results show that property process indicators and international systemic risk spillover measures were less significant for local banking sector financial condition.

It can lead to the conclusion that the problems of the group of less stable Polish big banks that are of the internal nature and are closely connected with the quality of their risk management procedures. That allow to prepare micro

and macroprudential instruments that allow to directly address issues of the excessive credit risk appetite, sensitivity to credit cycle and insufficient liquidity and interest rate term structure risk mitigation.

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Wskaźniki wczesnego ostrzegania przed niestabilnością finansową polskiego sektora bankowego

Streszczenie

W artykule została zaprezentowana sformalizowana procedura wyboru wskaźników wczesnego ostrzegania (WWO) przed niestabilnością finansową krajowego sektora bankowego. Zaproponowane podejście składa się z dwóch etapów. W ramach pierwszego z nich zbiór mikroostrożnościowych szeregów czasowych (obejmujących zebrane w latach 2007–2018 miary adekwatności kapitałowej, ryzyka kredytowego, koncentracji, ryzyka rynkowego i zyskowności) opisujących kondycję finansową grupy największych polskich banków został wykorzystany do określenia prawdopodobieństw ich niewypłacalności. Miary niewypłacalności wspomnianych instytucji finansowych następnie wykorzystano do opracowania indywidualnych wskaźników stabilności. Finalnie przedmiotowe wskaźniki stabilności posłużyły do wyboru z grupy potencjalnych szeregów czasowych (należących do obszaru zmiennych makroekonomicznych,

miar charakteryzujących krajowy sektor finansowy i stopień jego powiązania ze światowym systemem finansowym, a także wskaźników cen nieruchomości mieszkaniowych i komercyjnych) wskaźników wczesnego ostrzegania przed niestabilnością finansową polskiego sektora bankowego. Selekcja WWO została dokonana na podstawie wyników estymacji modelu regresji panelowej. Jakość wyprzedzających miar niestabilności (w relacji do referencyjnego wskaźnika luki kredytu w relacji do PKB) zweryfikowano za pomocą statystyki opartej na wielkości pola pod krzywą ROC (AUROC), co pozwoliło ustalić, że jako najbardziej efektywne można traktować wskaźniki luki kredytu udzielonego przez banki w relacji do PKB (wskaźnik odzwierciedlający cykl finansowy) oraz *spread* stopy zwrotu z 10-letnich obligacji rządowych i stopy WIBOR 3M (wskaźnik ryzyka płynności i ryzyka stopy procentowej). Zgodnie z wiedzą autora, przeprowadzona na potrzeby niniejszego artykułu analiza jest pierwszym badaniem, w ramach którego dla krajowego sektora bankowego opracowano dwuetapową procedurę selekcji makroostrożnościowych wskaźników wczesnego ostrzegania za pomocą modeli panelowej regresji wykorzystujących mikroostrożnościowe wskaźniki stabilności finansowej indywidualnych banków.

Słowa kluczowe: analiza makroostrożnościowa, wskaźniki wczesnego ostrzegania, analiza danych panelowych