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TVAR-Models of Financial Security Indicators for Macroeconomic Systems: Impact Assessment of Energy "Shock"

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Abstract. The break of connections in economic systems results in imbalance and a theoretical possibility of a threat for their development. This raises the issue of finding an effective mechanism for economic security in general and financial security in particular, which are important elements of how macroeconomic components work. The purpose of the study is to develop models that allow assessing the impact of an energy "shock" on financial security indicators, to identify the threshold values of exogenous variables at which the "shock" has a destructive influence on the level of financial security and can lead to the financial system destabilization. The work uses a branched structure of scientific methods which consist of theoretical and empirical research of the financial security for macroeconomic systems. The main results of this work are devoted to the consideration of the problem of how to design effective mechanisms for ensuring financial security under the conditions of exogenous "shocks" of the global economy. It considers the concept of "shock" and gives the examples of the impact of "shocks" on macroeconomic indicators. The work highlights the energy "shock" as dominant for the analysis and formation of an effective macroeconomic stability policy. The information area of research features is substantiated, including BRENT oil price data and indicators of monetary and currency security, such as the rate of inflation and the exchange rate. Emphasis on subsystems of monetary credit and currency security is made due to the importance of these channels of crisis infection in order to ensure financial security. The value of the lag in the model is substantiated with the help of information criteria; evaluation and testing of the quality of the model have been carried out; system stability has been assessed based on the impulse response function, the TVAR model has been developed. The areas of change of the exogenous variable reflecting the statistically significant impact of the energy "shock" on the rate of inflation are analyzed. Thus, the obtained results made it possible to identify the regimes of energy security, which become a channel of infection of the financial sphere and a significant increase in the level of inflation. Practical significance includes the versatility and applicability of the evaluation approach for research due to the ability to use the entire algorithm as a complete ensemble of models. The results of this material can be used in the formation of government financial security policies and reactions to destabilizing external influences

Keywords: security of macro-regions, risks and threats, security indicators of macroeconomic, oil price, threshold regimes

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INTRODUCTION

The current stage of economic development is characterized by strengthening globalization processes. The latter carry a number of advantages and, at the same time, pose new threats and risks that require an adequate adaptation of existing management systems to ensure sustainable functioning and development of macroeconomic systems. Thus, as a metric of increasing the efficiency of production and economic systems functioning as a result of globalization processes, we can single out the graphical exponential model of the world economy growth observed in the last 30 years (Fig. 1) [1].

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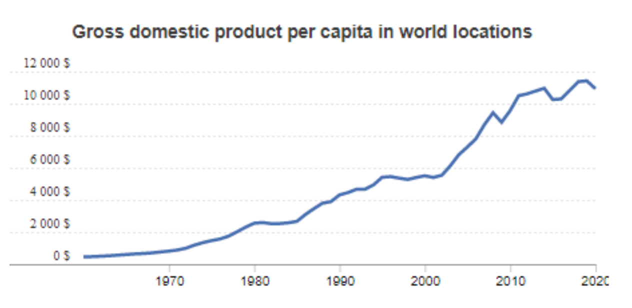
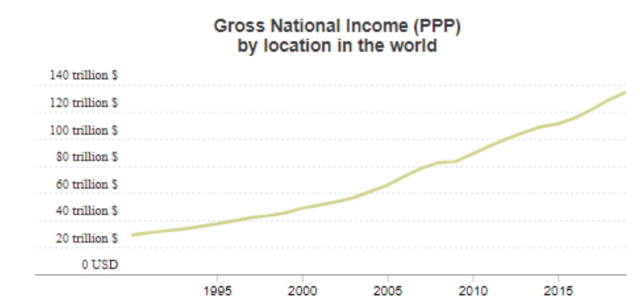


a) Dynamics of Gross Domestic Product per capita in the period of 1960-2020

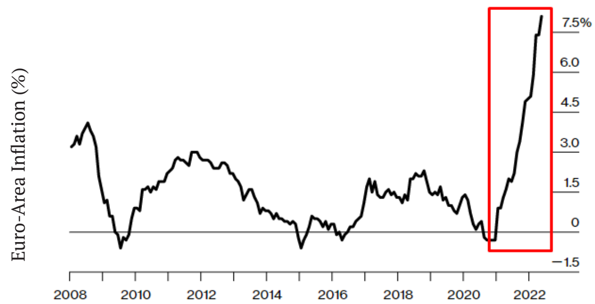


b) Dynamics of Gross National Income per capita in the period of 1985-2019

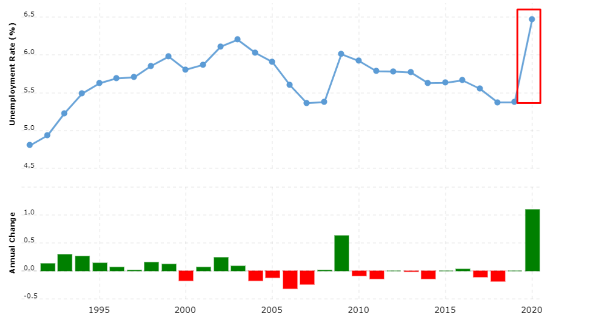
Figure 1. Factors of improving the general well-being of the global population expressed in income terms

Source: [1]

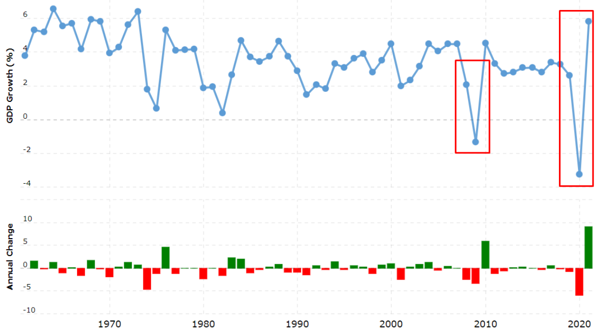
The exponential growth model of the world economy has become possible due to the high mobility of labor and capital resulting from globalization, the speed of innovation, etc. At the same time, due to the lack of formal borders the global economy creates new types of risks and threats, which, at a certain point, can lead to an increase in the probability of "shocks" which are understood as extraordinary stimuli (factors) that make conditions for a sharp change in the modes of how economic systems work and lead to destabilization. In economic sphere, the expansion of "shocks" happens with the help of channels of distribution, where trade, information and financial channels are most often seen. As shown by numerous studies, the financial channel plays the key role since its "shocks" lead to the lasting negative security fluctuations and the formation of crisis situations. This raises the question of how the "shocks" influence the financial security indicators of macroeconomic systems [2]. Figure 2 shows the application of the impact of different "shocks" on the indicators of economic security, namely, financial security of macro-regions.



a) Inflation in the Eurozone, the period of 2008-2022



b) The level of the world unemployment, the period of 1990-2020



c) the level of the world rate of GDP growth, the period of 1960-2020.

Figure 2. The impact of "shock" on certain macroeconomic indicators

Source: [3; 4]

The period of 2022 is characterized by the energy "shock" produced by the disruption of standard supply chains of raw materials, the restrictions in the movement of payments and capital investments, the international isolation of territories that were the main suppliers of energy resources in past years. The increased impact of the energy "shock" is confirmed by the dynamics of the price per barrel of BRENT oil shown in Figure 3.

Figure 3. Graphical interpretation of the energy "shock" in BRENT oil prices in US dollars

Source: [5]

In the current conditions, one of the urgent tasks of financial security management is the assessment of the impact of the energy "shock" on the dynamics of financial security indicators, the scenario analysis of its possible consequences in order to choose adequate tools for ensuring macroeconomic stability.

When evaluating [5], it should be emphasized that in the first quarter of 2022, the so-called energy "shock" took place in the world economy resulted from the change in the situation on international markets. The key supplier of energy resources, the Russian Federation, as a result of the military invasion into Ukraine, found itself under international economic sanctions and significantly reduced the export of oil, gas and other resources. In such conditions, there was a significant decrease in supply of energy resources due to the lack of adequate replacement of the reduced energy carriers, that, in its turn, brought about an increase in demand and prices.

Also, in 2020, as an exit measure from the international lockdown caused by COVID-19, the world financial system was given a boost to economic growth. These infusions made it possible the prognosticated effect of renewal, though, the surplus of money resulted in the incremental rise in inflationary pressures.

Thus, the prices for energy resources and inflation have resonated. This work reconsiders the hypothesis about a significant impact of "shock" in energy security on the pace of inflation expectations.

LITERATURE REVIEW

A significant number of publications are dedicated to the financial security of macroeconomic systems both in Ukrainian and foreign scientific literature. The author M. Ermoshenko [6] sees financial security as the state of financial and credit system of the country, the balance between all financial instruments and draws attention to the mandatory condition of being resistant to the influence of destabilizing factors. P. Mekshun [7] emphasized the combination of economic and financial security, where the specified elements are accepted as parts for the formation of sustainable development and general well-being. As the analysis of the sources showed, special attention is paid to the implementation of the system of indicators in the formation of financial security mechanisms, for example, the source [8]. Some of the foreign authors try to describe financial security through a retrospective view of crisis phenomena [9], the study of systemic risk in the markets [10]. However, the most widespread vision of the formation of mechanisms for ensuring the financial security of macroeconomic systems can be found in combination with economic and mathematical methods. Thus, the author O. Faryna [11] considers financial security through the prism of financial stability; uses a vector model to diagnose the stability of Ukraine's financial security. In the work of Yu. Bazhenova [12], the research focus is on the formation of a dynamic stochastic model of economic equilibrium that takes into account the impact of monetary and fiscal policies on the security of the country as a whole. The team of authors led by L. Guryanova [13] dwelled on the application of VAR (Vector Autoregressive Model) and ECM (Error Correction Model) to analyze the effects of the impact of "shocks" on the economic and financial security of macroregions through the justification of the system of indicators and the formation of a comprehensive assessment of security levels. Works of scientists [14; 15] investigate the possibility of using TVP-VAR models to assess the consequences of the impact of "shocks".

Summarizing the analysis of scientific viewpoints, we should mention the unconditional effectiveness of the approaches proposed by the authors and the prospects of using various modifications of VAR-modeling technologies to study the impact of "shocks" on indicators of financial security [16; 17]. At the same time, it should be noted that the existing viewpoints do not fully consider the issue of assessing the impact of energy "shock" [18; 19] on indicators of financial security, therefore the model evaluation apparatus has been improved. Furthermore, a new theoretical and practical approach to the combination of the model basis has been developed.

The purpose of the study is to develop models that allow assessing the impact of an energy "shock" on indicators of financial security, to identify threshold values of exogenous variables at which the "shock" has a destructive nature on the level of financial security and can lead to destabilization of the financial system.

MATERIALS AND METHODS

As mentioned above, the VAR model is an effective tool for building a model of the dynamics of financial security indicators. The choice of this mathematical toolkit is due to the possibility of modeling interdependent variables evaluating the impact of "shocks" on economic dynamics. Construction of the VAR model includes the following stages: checking time series for stationarity using the Dickey-Fuller test; determining the order of integration and adjustment of variables; testing for the nature of causal relationships based on the Granger test; evaluation and determination of the order (lag) of the VAR model; construction of impulse functions, decomposition of variances and assessment of system stability [20]. The work uses such a modification of the VAR model as the TVAR model (Threshold Vector Autoregressive Model) that allows determining the threshold values of exogenous indicators which, when exceeded, will lead to the destructive impact of "shocks" on the financial security of economic systems.

In order to estimate the energy "shock" it is proposed to select data on the cost of the most important resource of this type – oil, or more precisely – the cost of 1 barrel of BRENT oil for the monthly periods from January 2012 to March 2022 [5]. As financial security indicators we consider monetary and currency security indicators (inflation rates and the value of the dollar exchange rate) since it is exactly the currency security that remains the main critical subsystem of financial security for the national economy if we turn to countries with developing economies [21-23]. Data processing has been carried out in the EViews environment.

At the stages of the preliminary analysis, the time series have been tested for stationarity, have been transformed and then analyzed for the presence of two-way causal relationships. The presence of significant relationships has been confirmed. The created VAR model includes three factors: the rate of inflation (INFLATION_LEVEL), the dollar exchange rate (EXCHANGE_RATE), the price of one barrel of BRENT oil (BRENT_PRICE). The results of its implementation are considered below.

Results and Discussion

Figure 4 features the definition of the lag order of the model which is based on the analysis of various statistical criteria [24; 25]. Statistics of the value of the logarithmic probability (LogL), modified linear regression (LR), final prediction error (FPE), Akaike information criteria (AIC), Schwartz (SC) and Hannan-Quinn (HQ) have been considered [26; 27]. Optimal values marked with (*) are automatically selected for each of the criteria. Thus, it is determined that the lag which should be taken into account in the model, equals 3.

Sample: 2012M01 2022M03
Included observations: 115

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-1082.765	NA	31864.03	18.88286	18.95447	18.91193
1	-749.3572	643.6213	113.0067	13.24099	13.52742	13.35725
2	-727.2816	41.46377	90.05434	13.01359	13.51484	13.21705
3	-670.2232	104.1936	39.07505*	12.17779*	12.89386*	12.46844*
4	-665.5671	8.259527	42.20845	12.25334	13.18423	12.63118
5	-655.4725	17.38029*	41.51780	12.23430	13.38001	12.69934
6	-652.2327	5.408980	46.06351	12.33448	13.69501	12.88671
7	-649.7239	4.057632	51.83471	12.44737	14.02273	13.08680
8	-639.0471	16.71165	50.69002	12.41821	14.20838	13.14483

Figure 4. Determination of the VAR model lag order

Source: author's calculation.

Figure 5 presents the quality criteria of the developed vector autoregression model. The coefficients of determination (R-squared) for the variables INFLATION_LEVEL, EXCHANGE_RATE and BRENT_PRICE are close to 1, which indicates the statistical significance of the model. The values of Fisher's test (F-statistic), which exceed those in the table, confirm the adequacy of the developed model. The information criteria of Akaike and Schwartz also show good prognostic properties of the model (Fig. 5) [20].

```
Estimation Proc:
===============================
LS 1 3 INFLATION_LEVEL EXCHANGE_RATE BRENT_PRICE

VAR Model:
===============================
INFLATION_LEVEL = C(1,1)*INFLATION_LEVEL(-1) + C(1,2)*INFLATION_LEVEL(-2) + C(1,3)*INFLATION_LEVEL(-3)
+ C(1,4)*EXCHANGE_RATE(-1) + C(1,5)*EXCHANGE_RATE(-2) + C(1,6)*EXCHANGE_RATE(-3) +
C(1,7)*BRENT_PRICE(-1) + C(1,8)*BRENT_PRICE(-2) + C(1,9)*BRENT_PRICE(-3) + C(1,10)

EXCHANGE_RATE = C(2,1)*INFLATION_LEVEL(-1) + C(2,2)*INFLATION_LEVEL(-2) + C(2,3)*INFLATION_LEVEL(-3)
+ C(2,4)*EXCHANGE_RATE(-1) + C(2,5)*EXCHANGE_RATE(-2) + C(2,6)*EXCHANGE_RATE(-3) +
C(2,7)*BRENT_PRICE(-1) + C(2,8)*BRENT_PRICE(-2) + C(2,9)*BRENT_PRICE(-3) + C(2,10)

BRENT_PRICE = C(3,1)*INFLATION_LEVEL(-1) + C(3,2)*INFLATION_LEVEL(-2) + C(3,3)*INFLATION_LEVEL(-3) +
C(3,4)*EXCHANGE_RATE(-1) + C(3,5)*EXCHANGE_RATE(-2) + C(3,6)*EXCHANGE_RATE(-3) +
C(3,7)*BRENT_PRICE(-1) + C(3,8)*BRENT_PRICE(-2) + C(3,9)*BRENT_PRICE(-3) + C(3,10)

VAR Model - Substituted Coefficients:
===============================
INFLATION_LEVEL = 0.438447584574*INFLATION_LEVEL(-1) + 0.158505760963*INFLATION_LEVEL(-2) -
0.0868431261887*INFLATION_LEVEL(-3) + 0.568543812643*EXCHANGE_RATE(-1) +
0.291841547235*EXCHANGE_RATE(-2) - 0.838807204011*EXCHANGE_RATE(-3) +
0.0207757708347*BRENT_PRICE(-1) - 0.0109919589974*BRENT_PRICE(-2) - 0.00296559796249*BRENT_PRICE(-3)
+ 48.3904777273

EXCHANGE_RATE =  - 0.0829800505089*INFLATION_LEVEL(-1) + 0.0776172355092*INFLATION_LEVEL(-2) -
0.0174432659277*INFLATION_LEVEL(-3) + 0.746175834427*EXCHANGE_RATE(-1) +
0.117783630736*EXCHANGE_RATE(-2) + 0.0945740830162*EXCHANGE_RATE(-3) -
0.0508429086177*BRENT_PRICE(-1) + 0.00216883719847*BRENT_PRICE(-2) + 0.0330982928849*BRENT_PRICE(-
3) + 4.336569392

BRENT_PRICE = 0.245688352967*INFLATION_LEVEL(-1) - 0.0187151534869*INFLATION_LEVEL(-2) -
0.289656752208*INFLATION_LEVEL(-3) - 0.365866693344*EXCHANGE_RATE(-1) +
0.592851352855*EXCHANGE_RATE(-2) - 0.115695014751*EXCHANGE_RATE(-3) + 1.41632909325*BRENT_PRICE(-
1) - 0.657665155961*BRENT_PRICE(-2) + 0.245038652133*BRENT_PRICE(-3) + 3.8750237335
```

a) alignment of the VAR model

R-squared	0.786643	0.974134	0.930645
Adj. R-squared	0.769187	0.972018	0.924970
Sum sq. resids	89.13179	186.0535	2540.697
S.E. equation	0.900161	1.300537	4.805959
F-statistic	45.06319	460.2973	164.0038
Log likelihood	-152.4301	-196.5852	-353.4347
Akaike AIC	2.707168	3.443086	6.057246
Schwarz SC	2.939459	3.675377	6.289537
Mean dependent	100.9983	21.54775	59.20242
S.D. dependent	1.873656	7.774639	17.54539

b) quality criteria

Figure 5. Results of building a vector autoregression model

Source: author's calculation

Figure 6 presents the accuracy criteria of the forecast obtained on the basis of the VAR model. Thus, the value of the average absolute percentage error of the model (MAPE) for the identified factors is less than 10% which corresponds to high forecasting accuracy. Figure 7 presents the result of constructing an impulse function which shows the response of variables in response to a "shock" – a change in the random component of the time series of the price of one barrel of oil by one standard deviation.

Sample: 2012M01 2022M03
Included observations: 123

Variable	Inc. obs.	RMSE	MAE	MAPE	Theil
BRENT_PRICE	123	4.601356	3.251012	5.834693	0.037324
EXCHANGE_RATE	123	1.245169	0.737817	3.972493	0.027211
INFLATION_LEV...	123	0.861838	0.643935	0.635887	0.004266

Figure 6. Predictive characteristics of the VAR model

Source: author's calculation

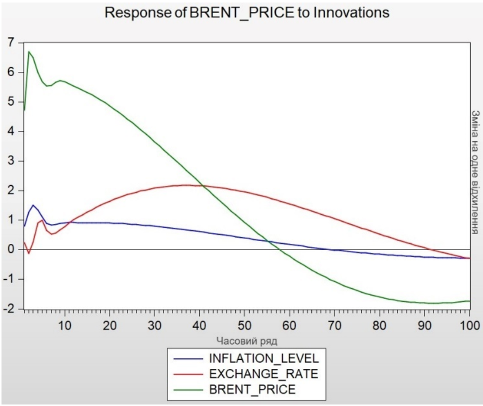


Figure 7. Graphs of impulse functions

Source: author's calculation

The data of Figure 7 allow us to confirm the hypothesis about the significant impact of the energy "shock" on such indicators of financial security as the inflation rate and the exchange rate. Then, the hypothesis that this influence is differentiated at different threshold values of the exogenous variable has been put forward. We used the TVAR model to test the hypothesis. Figure 8 shows the parameters of the developed threshold vector autoregression where the price of BRENT oil per barrel is presented as a threshold value.

Sample: 2012M01 2022M03
Included observations: 123
Selection: Trimming 0.15, , Sig. level 0.05
Threshold variable: BRENT_PRICE

Variable	Coefficient	Std. Error	t-Statistic	Prob.
BRENT_PRICE < 44.799999 -- 29 obs				
INFLATION_LEVEL	-0.466858	0.649188	-0.719141	0.4736
EXCHANGE_RATE	-0.938991	0.280474	-3.347870	0.0011
C	108.5901	67.66992	1.604703	0.1115
44.799999 <= BRENT_PRICE < 55.109999 -- 26 obs				
INFLATION_LEVEL	-0.113164	0.343972	-0.328993	0.7428
EXCHANGE_RATE	0.034500	0.291007	0.118554	0.9058
C	61.43795	37.10701	1.655697	0.1007
55.109999 <= BRENT_PRICE < 65.769999 -- 26 obs				
INFLATION_LEVEL	-0.336199	0.291511	-1.153298	0.2513
EXCHANGE_RATE	0.035884	0.267074	0.134360	0.8934
C	92.57136	32.50633	2.847794	0.0053
65.769999 <= BRENT_PRICE < 83.369999 -- 24 obs				
INFLATION_LEVEL	-0.246459	0.704735	-0.349719	0.7272
EXCHANGE_RATE	-0.461196	0.099506	-4.634846	0.0000
C	107.9939	70.91044	1.522963	0.1307
83.369999 <= BRENT_PRICE -- 18 obs				
INFLATION_LEVEL	6.501979	1.644053	3.954847	0.0001
EXCHANGE_RATE	-0.580837	0.272392	-2.132355	0.0352
C	-558.3694	162.4583	-3.437002	0.0008

R-squared	0.961744	Mean dependent var	59.96382
Adjusted R-squared	0.956785	S.D. dependent var	17.99863
S.E. of regression	3.741576	Akaike info criterion	5.590740
Sum squared resid	1511.934	Schwarz criterion	5.933690
Log likelihood	-328.8305	Hannan-Quinn criter.	5.730045
F-statistic	193.9373	Durbin-Watson stat	1.564185
Prob(F-statistic)	0.000000		

Figure 8. The result of building the TVAR model

Source: author's calculation

Among the obtained results of the threshold vector atoregression, the greatest practical value belongs to the ones where the inflation and exchange rate parameters are statistically significant. This condition corresponds to the range where BRENT_PRICE > $83.37. That is, if the price of oil is higher than the specified numerical value, then there is a statistically significant change in inflation and the dollar exchange rate. Thus, the TVAR model allows us to determine the threshold value of the cost of energy resources which, when exceeded, can lead to a destabilizing effect on the financial system and become a threat to monetary and currency security.

Drawing parallels with works [28-30], we can talk about the implementation of an atypical approach to assessing the financial security of macroeconomic systems. In works [31; 32], the authors provide a vision of the global economy through the use of macroeconomic modeling that implements generalized calculation algorithms. Sources [33-35], on the other hand, have common key features with this work, but local systems of economic indicators are considered without reference to global macroeconomic shifts. This paper presents a study of a separate "shock" in the energy sector, which is quite difficult to predict using standard approaches of VAR or ECM models. Therefore, the chosen implementation strategy definitely has made it possible to obtain significant practical results of forecasting macroeconomic parameters.

CONCLUSIONS

The paper explores the possibilities of using the TVAR model (Threshold Vector Autoregressive Model) to assess the impact of an energy "shock" on indicators of financial security, in particular, on monetary and currency security. The model has been tested on the data of the country representing a cluster of countries with a developing economy. The results of modeling made it possible to identify critical modes of energy security which are becoming a channel of infection that the crisis may spread in the financial sphere and the cause of a significant increase in the level of inflation. The determined threshold values of prices for energy resources can be used as a marker in the development of energy policy which makes it possible to ensure macroeconomic stability. The prospect of further research is the development of ways to use a list of exogenous variables for testing subsystems of financial security for manifestations of various types of "shocks" and the implementation of scenario analysis of macroeconomic systems behavior.

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TVAR-моделі індикаторів фінансової безпеки макроекономічних систем: оцінка впливу енергетичного "шоку"

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Анотація. При порушенні зв'язків в економічних системах виникає розбалансування та існує теоретична ймовірність загрозливого стану для їх розвитку. Звідси постає питання проблематики пошуку ефективного механізму економічної безпеки загалом та фінансової безпеки зокрема є важливими елементами роботи макроекономічних складових. Метою дослідження є розробка моделей, що дозволяють оцінити вплив енергетичного «шоку» на індикатори фінансової безпеки, виявити порогові значення екзогенних змінних, при яких «шок» має деструктивний характер на рівень фінансової безпеки та може призвести до дестабілізації фінансової системи. У роботі використано розгалужену структуру наукових методів, які полягають у теоретичному та емпіричному дослідженні фінансової безпеки макроекономічних систем. Основні результати роботи присвячені розгляду проблеми проектування ефективних механізмів забезпечення фінансової безпеки за умов дії екзогенних «шоків» глобальної економіки. Розглянуто поняття «шоку», наведено приклади впливу «шоків» на макроекономічні індикатори. У роботі виділено енергетичний «шок» як домінантний для аналізу та формування ефективної політики макроекономічної стабільності. Обґрунтовано інформаційний простір ознак дослідження, що включає дані ціни на нафту марки BRENT та такі індикатори грошово-кредитної та валютної безпеки, як темп інфляції та валютний курс. Акцент на підсистемах грошово-кредитної та валютної безпеки зроблено через значущість даних каналів інфікування кризою задля забезпечення фінансової безпеки. Обґрунтовано величину лага в моделі за допомогою інформаційних критеріїв; проведено оцінювання та тестування якості моделі; здійснено оцінку стабільності системи на основі функції імпульсних відгуків, розроблено TVAR-модель. Проаналізовано галузі зміни екзогенної змінної, що відображають статистично значущий вплив енергетичного «шоку» на темп інфляції. Таким чином, отримані результати дозволили виділити режими енергетичної безпеки, які стають каналом інфікування фінансової сфери та суттєвого зростання рівня інфляції. Практична значущість включає універсальність та можливість застосування підходу оцінки для досліджень через можливість використовувати увесь алгоритм як повноцінний ансамбль моделей. Результати даного матеріалу можуть використані при формуванні державних політик фінансової безпеки та реакції на дестабілізуючі зовнішні впливи

Ключові слова: безпека макрорегіонів, ризики та загрози, індикатори безпеки, ціна нафти, порогові режими