

https://doi.org/10.51885/3134-8025_IJCS_2026_3_12

SRSTI 28.23.24

AUTOMATION OF DECISION-MAKING IN INTELLIGENT CONTROL SYSTEMS USING A HYBRID: BAYESIAN–SARIMAX MODEL FOR CREDIT RISK FORECASTING

ГИБРИДТІ ПАЙДАЛАНҒАН ЗИЯЛДЫ БАСҚАРУ ЖҮЙЕЛЕРІНДЕ
ШЕШІМ ҚАБЫЛДАУ ДЫ АВТОМАТТАНДЫРУ: КРЕДИТТІК
ТӘУЕКЕЛДІ БОЛЖАУҒА А
РНАЛҒАН БАЙЕС-САРИМАКС ҮЛГІСІ

АВТОМАТИЗАЦИЯ ПРИНЯТИЯ РЕШЕНИЙ В ИНТЕЛЛЕКТУАЛЬНЫХ
СИСТЕМАХ УПРАВЛЕНИЯ С ИСПОЛЬЗОВАНИЕМ ГИБРИДНОЙ:
БАЙЕСОВСКО-САРИМАКСОВОЙ МОДЕЛИ
ДЛЯ ПРОГНОЗИРОВАНИЯ КРЕДИТНОГО РИСКА

A. Shayakhmetova ¹, A. Akhmetova ¹, N. Abdurakhmanov ^{1*}

¹Al-Farabi Kazakh National University, Almaty, Kazakhstan

*Corresponding author: Nurken Abdurakhmanov, e-mail: ngsn4246@gmail.com

keywords:

Bayesian model;
SARIMAX; intelligent
control systems; hybrid
forecasting; decision-
making automation; credit
risk; macrofinancial
transmission; forecasting of
loan defaults.

ABSTRACT

For automating decision-making systems, we need models that learn from complex and dynamic macroeconomic factors. In this research, we propose a hybrid forecasting framework, Bayes-Sarimax. This method incorporates forecasts of dynamic time series probabilities. The aim is to improve credit risk assessment accuracy and increase explainability. The model includes linear dependencies between loan defaults and macroeconomic factors. These factors include inflation, general citizen income, salaries, rising GDP, and the relationship between private loans and GDP.

The model was learned and validated using real macroeconomic data. This data originated from a bank portfolio and encompassed both national and international sources. To rate macroeconomic stress due to loan defaults, we used lagged correlations, causal dependency, and impulse reactions. Bayesian layers improve the quality of models on limited data. They include a priori distributions and quantify uncertainty. Sarimax adds explainable time dynamics.

Experimental results show the hybrid model outperforms classical SARIMAX and autonomous Bayesian models. It does better in both forecasting accuracy and clarity of decision support. This environment provides more reliable automation of credit-related decisions in intelligent control systems. It supports the development of adaptive, data-driven financial control systems.

Түйінді сөздер:

Байес үлгісі; SARIMAX;
интеллектуалды басқару
жүйелері; гибридті

ТҮЙІНДЕМЕ

Шешім қабылдау жүйелерін автоматтандыру үшін бізге күрделі және динамикалық макроэкономикалық факторлардан сабақ алатын модельдер қажет. Бұл зерттеуде біз Bayes-Sarimax гибридті



болжау; шешімдер
қабылдауды
автоматтандыру; несиелік
тәуекел; макроқаржылық
трансмиссия; несие
бойынша дефолтты
болжау.

әдісті іздедік. Бұл әдіс динамикалық уақыт қатарларының ықтималдықтарының болжамдарын біріктіреді. Мақсат – несиелік тәуекелді бағалаудың дәлдігін арттыру және түсініктілігін арттыру. Модель несие дефолттары мен макроэкономикалық факторлар арасындағы сызықтық тәуелділікті қамтиды. Бұл факторларға инфляция, азаматтардың жалпы табысы, жалақы, ЖІӨ өсуі және жеке несиелер мен ЖІӨ арасындағы қатынас жатады.

Модель нақты макроэкономикалық деректер арқылы зерттелді және расталды. Бұл деректер банк портфелінен алынған және ұлттық және халықаралық көздерді қамтиды. Несие бойынша дефолтқа байланысты макроэкономикалық күйзелісті бағалау үшін біз кешіктірілген корреляцияларды, себептік тәуелділікті және импульстік реакцияларды қолдандық. Байес қабаттары шектеулі деректердегі үлгілердің сапасын жақсартады. Олар априорлық үлестіруді қамтиды және белгісіздікті анықтайды. Sarimax түсіндірілетін уақыт динамикасын қосады.

Эксперимент нәтижелері гибриді үлгінің классикалық SARIMAX және аутономды Байес үлгілерінен асып түсетінін көрсетеді. Ол болжау дәлдігінде де, шешімдерді қолдаудың анықтығында да жақсырақ жұмыс істейді. Бұл орта интеллектуалды басқару жүйелерінде кредитке қатысты шешімдерді сенімдірек автоматтандыруды қамтамасыз етеді. Ол бейімделгіш, деректерге негізделген қаржылық бақылау жүйелерінің дамуын қолдайды.

Ключевые слова:

Байесовская модель;
SARIMAX;
интеллектуальные
системы управления;
гибридное
прогнозирование;
автоматизация принятия
решений; кредитный
риск; макрофинансовая
трансмиссия;
прогнозирование
невозврата кредитов.

АННОТАЦИЯ

Для автоматизации систем принятия решений необходимы модели, обучающиеся на основе сложных и динамических макроэкономических факторов. В данном исследовании мы искали гибридный метод Байеса-Саримакс. Этот метод включает прогнозирование вероятностей динамических временных рядов. Целью является повышение точности оценки кредитного риска и повышение объяснимости. Модель учитывает линейные зависимости между дефолтами по кредитам и макроэкономическими факторами. К таким факторам относятся инфляция, общий доход граждан, заработная плата, рост ВВП и взаимосвязь между частными кредитами и ВВП.

Модель была обучена и валидирована с использованием реальных макроэкономических данных. Эти данные были получены из банковского портфеля и охватывали как национальные, так и международные источники. Для оценки макроэкономического стресса, вызванного дефолтами по кредитам, мы использовали лаговые корреляции, причинно-следственные зависимости и импульсные реакции. Байесовские слои улучшают качество моделей на ограниченных данных. Они включают априорные распределения и количественно оценивают неопределенность. Саримакс добавляет объяснимую временную динамику.

Экспериментальные результаты показывают, что гибридная модель превосходит классическую модель SARIMAX и автономные байесовские модели. Она повышает точность прогнозирования и прозрачность поддержки принятия решений. Эта среда обеспечивает более надежную автоматизацию решений, связанных с кредитованием, в интеллектуальных системах управления. Она поддерживает разработку адаптивных систем финансового контроля на основе данных.

INTRODUCTION

Developing the intelligent control system has become a key direction in science, modern technology, and data control. Increasing the complexity of social, economic, and technical systems necessitates an automated decision-making process that can adapt to rapidly changing conditions. In the financial sector, this problem is particularly evident in the area of credit risk management, where decisions must take into account uncertainty, macroeconomic shocks, and delayed feedback between internal and external factors. The main component of digital transformation is an intellectual system of forecasting that has the ability to explain those relations and support automated decision-making.

Traditional time-series models, such as seasonal autoregressive integrated moving average with exogenous factors (SARIMAX), are widely used for explaining and forecasting complex time dynamics. The time series models demonstrated very good accuracy in different spheres, including energy consumption (Kachhalla et al., 2025), demand for tourism (Lee, 2025), monitoring temperature and environment (Shah et al., 2024), and short-term market forecasting (Banaś & Utnik-Banaś, 2021). Sarimax effectively includes exogenous variables, which makes it suitable for modelling macroeconomic relations. However, this classical time-series model's rate suggests constant parameters and can not probabilistically change the character of the economic process. As a result, we can see the weak side of Sarimax, which is not reliable enough for automated decision-making.

The scientific novelty of this research lies in integrating Bayesian probabilistic reasoning into the structure of SARIMAX, thereby providing explainability and including an undefined forecast within the range of intellectual control. The resulting model not only provides forecasts but also presents information about changes in macroeconomic shocks. In practice, the model would be realized in a composition of an automated module supporting intellectual system control in a bank's risk management system, which involves dynamically adjusting loan strategies in volatile economic conditions. The results have a significant impact on a wide range of intellectual control, due to the expansion of the methodological base, in line with Kazakhstan's national priority for digital economics and the global trend of explainable artificial intelligence in the economic system.

MATERIALS AND METHODS

The proposed hybrid, known as the Bayes-Sarimax method, incorporates econometric modeling with Bayesian probability learning to facilitate automated decision-making based on forecast results within an intelligent control system. The working process of the model was explained in Figure 1, which illustrates the integration of Sarimax time-series forecasting and Bayesian a posteriori updating into an intelligent control loop.

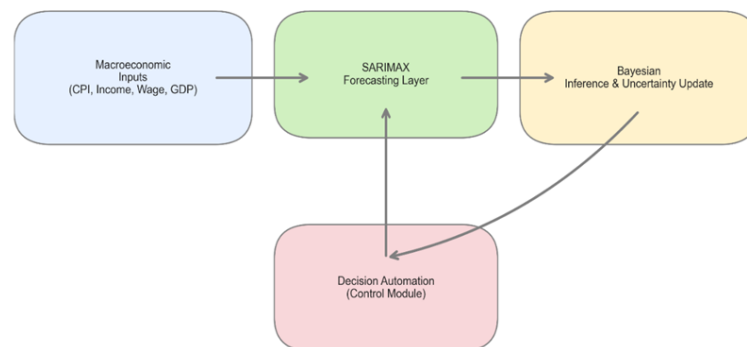


Figure 1. Conceptual structure of the hybrid: Bayesian-SARIMAX model integrated into an intelligent control system

In this scheme, the data stream is illustrated: macroeconomic internal data, which is sent to SARIMAX layers, then to Bayesian output and updating, and ultimately to automated decision making.

Sarimax forecast model

The Sarimax model includes linear dynamics like seasonal effects between loan defaults and exogenous macroeconomic indicators.

Models are defined with this formula:

$$Y_t = \mu + \sum_{i=1}^p \phi_i Y_{t-i} + \sum_{i=1}^q \theta_i \varepsilon_{t-i} + \sum_{k=1}^K \beta_k X_{k,t-d_k} + \varepsilon_t, \varepsilon_t \sim \mathcal{N}(0, \sigma^2)$$

where: Y_t — loan delinquency value at time t ;

μ — constant intercept term;

ϕ_i — autoregressive coefficients;

Y_{t-i} — lagged values of the target variable;

θ_i — moving-average coefficients;

ε_{t-i} — lagged residual errors;

β_k — coefficients of exogenous macroeconomic variables;

$X_{k,t-d_k}$ — exogenous macroeconomic variables with lag d_k ;

K — number of exogenous variables;

ε_t — white-noise error term distributed as $N(0, \sigma^2)$;

$N(0, \sigma^2)$ — normal (Gaussian) distribution;

mean = 0;

variance = σ^2 .

The final forecasting model was specified as SARIMAX(1,1,1)(1,1,1,12), where:

– (1,1,1) represents non-seasonal autoregressive, differencing, and moving-average components;

– (1,1,1,12) represents seasonal components with a 12-month seasonal period.

The model structure was selected based on autocorrelation function (ACF), partial autocorrelation function (PACF), and Akaike Information Criterion (AIC).

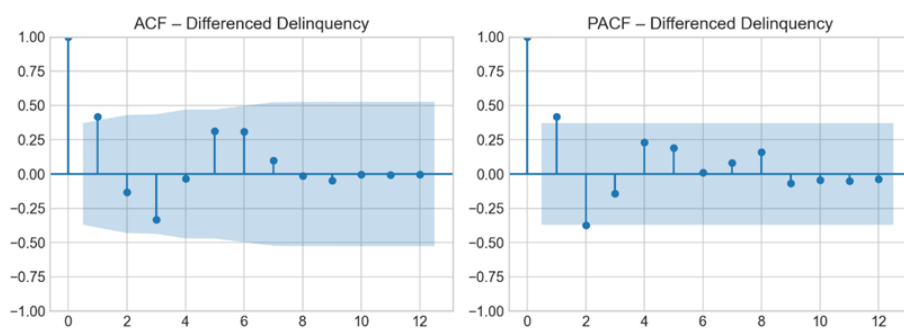


Figure 2. Residual diagnostics of the SARIMAX model, including ACF and PACF plots, were used to select the model order

The ACF and PACF diagnostics confirmed the presence of autoregressive seasonal patterns and justified the selected SARIMAX specification.

Residual diagnostics demonstrated the absence of significant autocorrelation, confirming the adequacy of the selected model specification.

The figure shows the autocorrelation function (ACF) and partial autocorrelation function (PACF) of the differential series for loan default.

This diagnostic is used for defining definite autoregression(p) and rolling mean(q) for the model SARIMAX. According to ACF and PACF, assume the structure of an AR with little effect of rolling mean, which shows the process of loan default for the first time, because of its own lags, not because of residual shocks. Absence of shocks outside of the lags proves that the residual values behave like white noise, by proving that the chosen model is suitable for specification.

Updating Bayes parameters

Taking into account the parameters, the Sarimax parameters were modeled in a Bayesian framework, where a posteriori, the bones are:

$$p(\theta, \beta | Y, X) \propto p(Y | X, \theta, \beta) p(\theta) p(\beta)$$

where: $p(\theta, \beta | Y, X)$ – posterior probability distribution of model parameters;

$p(Y | X, \theta, \beta)$ – likelihood function of observed data;

$p(\theta)$ – prior distribution of SARIMAX parameters;

$p(\beta)$ – prior distribution of macroeconomic coefficients;

θ – vector of SARIMAX parameters;

β – vector of Bayesian regression coefficients;

Y – observed loan delinquency values;

X – matrix of exogenous macroeconomic variables.

with Gaussian aprior probability:

$$\beta_k \sim \mathcal{N}(0, \tau^2), \phi_i \sim \mathcal{N}(0, 1)$$

where: β_k – Bayesian coefficients of macroeconomic variables;

ϕ_i – autoregressive SARIMAX parameters;

τ^2 – prior variance controlling parameter uncertainty.

Posterior inference was performed using Markov Chain Monte Carlo (MCMC) sampling to estimate the probability distributions of macroeconomic coefficients under uncertainty.

A total of 5000 MCMC iterations were performed to ensure convergence stability of posterior estimates.

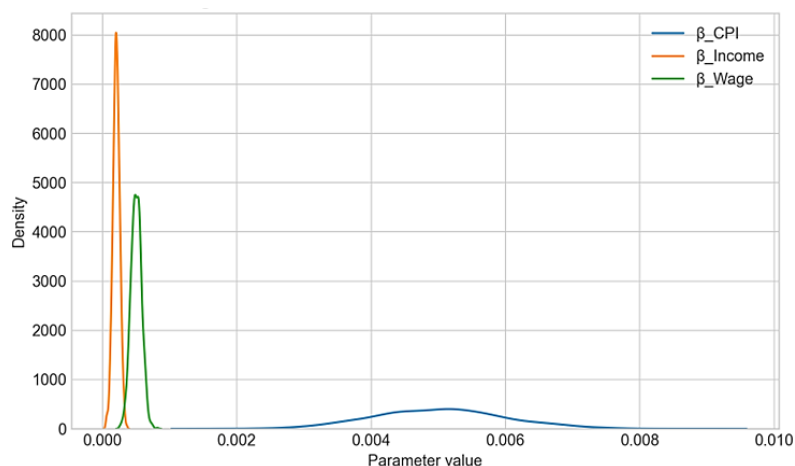


Figure 3. Posterior distributions of macrofactor coefficients

The figure shows the posterior distribution of the parameters β_k coefficients, illustrating uncertainty in macroeconomic effects.

Posterior distributions allow the model to quantify uncertainty in macroeconomic effects and improve adaptive decision-making under volatile economic conditions.

VAR and analysis of causal effects relations by Granger.

Within the hybrid architecture, the SARIMAX component captures temporal and seasonal macroeconomic dynamics, while the Bayesian layer updates parameter uncertainty and improves probabilistic interpretability under changing economic conditions.

We calculated a multidimensional model of vector autoregression (VAR) to establish causal effects, relations, and dynamic interdependencies:

$$\mathbf{Z}_t = \mathbf{A}_1 \mathbf{Z}_{t-1} + \mathbf{A}_2 \mathbf{Z}_{t-2} + \dots + \mathbf{A}_p \mathbf{Z}_{t-p} + \mathbf{u}_t, \mathbf{u}_t \sim \mathcal{N}(\mathbf{0}, \varsigma)$$

where: $\mathbf{Z}_t$ – vector of endogenous macroeconomic variables at time t ;

$\mathbf{A}_1, \dots, \mathbf{A}_p$ – coefficient matrices of lagged relationships;

$\mathbf{Z}_{t-1}, \dots, \mathbf{Z}_{t-p}$ – lagged endogenous variables;

p – lag order of the VAR model;

$\mathbf{u}_t$ – multivariate white-noise error vector distributed as $\mathcal{N}(\mathbf{0}, \Sigma)$

ς – covariance matrix of residuals.

where

$$\mathbf{Z}_t = [\mathbf{Y}_t, \mathbf{X}_{1,t}, \mathbf{X}_{2,t}, \mathbf{X}_{3,t}]^T$$

where: $\mathbf{Z}_t$ – vector of endogenous variables at time t ;

$\mathbf{Y}_t$ – loan delinquency indicator;

$\mathbf{X}_{1,t}$ – inflation indicator (CPI);

$\mathbf{X}_{2,t}$ – real household income indicator;

$\mathbf{X}_{3,t}$ – real wage indicator;

T – transpose operator.

vector endogenous variables. The Granger test of causal effects was used to investigate whether loan defaults have an influence on macroeconomic changes.

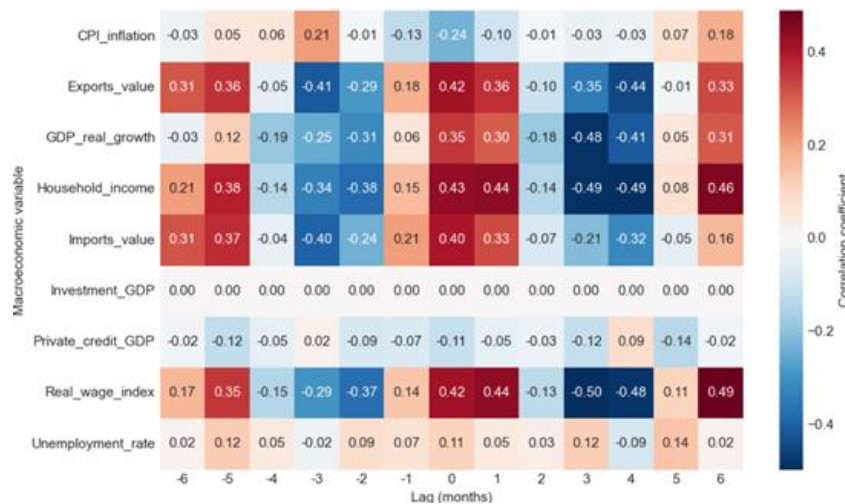


Figure 4. Heat map of cross-correlation (overdue debt vs. macroeconomic factors) based on lag correlation analysis

The heat map of mutual correlations displays the pairwise correlation coefficients between loan delinquency and key macroeconomic variables across a range of delays, from -6 to +6 months. Heat colours show positive correlations (macroeconomic factor rising after growing loan defaults), while cold colours show negative correlations. Strong positive lagged correlations exist between inflation and real income, illustrating that rising loan delinquency is outpacing inflation and decreasing the incomes of citizens for two to three months. This model shows that the time distribution of financial stress from the credit sector influences the real sectors of the economy.

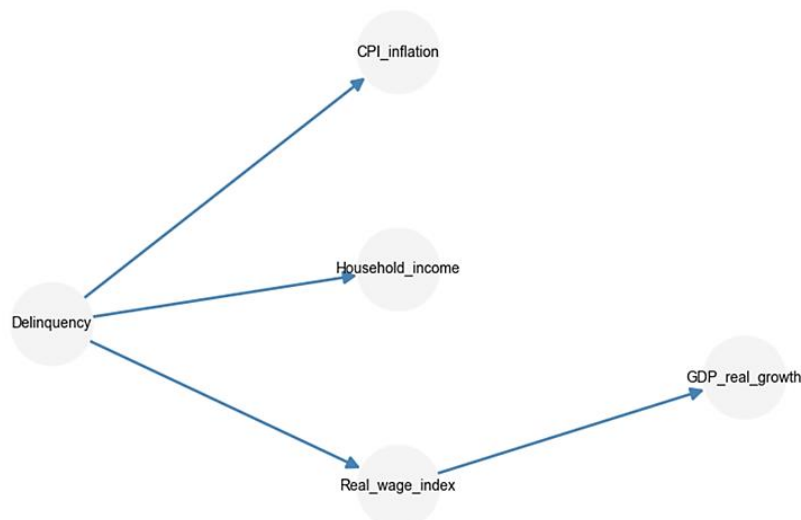


Figure 5. Causal diagram showing the directional effects from arrears to CPI, real income, and real wages, with spillovers to GDP

It is a network of cause and effect derived from the results of the Granger test. It shows a one-directional causal effect, where shocks of loan delinquency come into macroeconomic outcomes. Arrows from loan delinquency to inflation, real incomes, and salaries illustrate the main channel of transferring, where the loan-giving conditions influence the price level and the household income conditions. Secondary pathway from salaries to growth gdp shows influences on the dynamics of salaries to the volume of manufacturing. In general, it demonstrates how the microfinancial shocks propagate into macroeconomic fluctuations of the macrolevel.

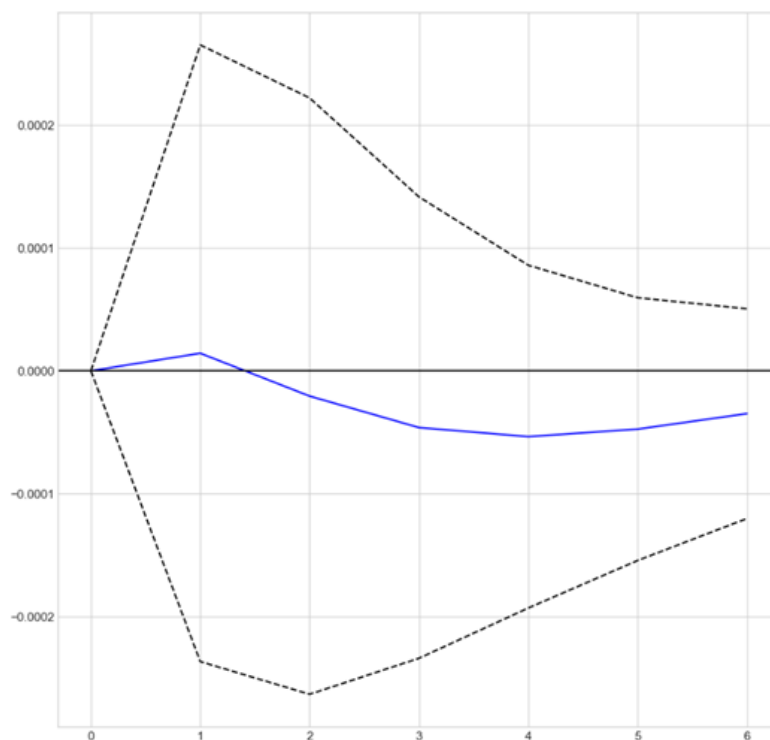


Figure 6. Impulse response functions (IRFs) illustrating the CPI inflation response to a one standard deviation arrears shock

IRF shows dynamic correction of inflation with exogenous rising by growing loan delinquency to one standard deviation. Here, it shows a increase in loan delinquency credits associated with inflation and tightening of conditions of credit loans, and an increase in risk premiums. The next phase is about the stabilisation of the short-term acceleration of price before returning to equilibrium.

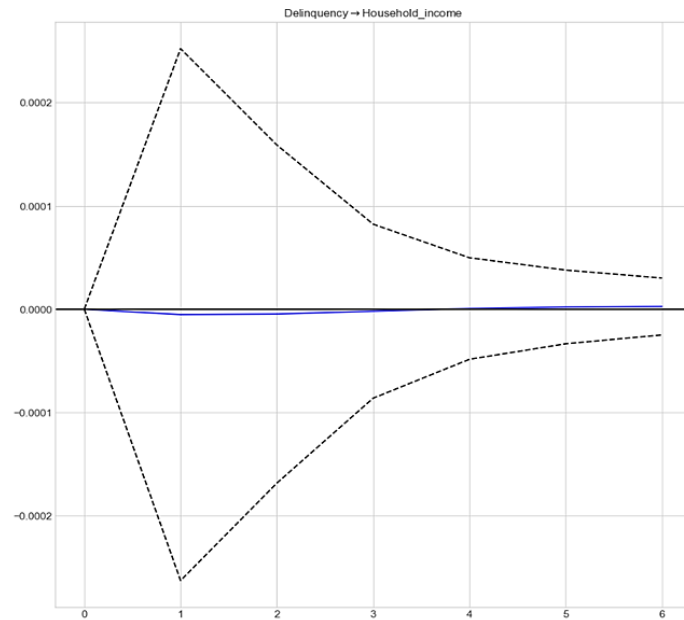


Figure 7. Overdue debt on population income

This image shows the lagged negative reaction of shocks of loan defaults. About two to three months after the initial growth of defaults, the income of citizens is falling, because household financial constraints intensify and unemployment in the employment sphere. Recovery phase, observed in later periods, involves adaptive corrections of salaries or political interference, which soften the lingering impact of financial difficulties.

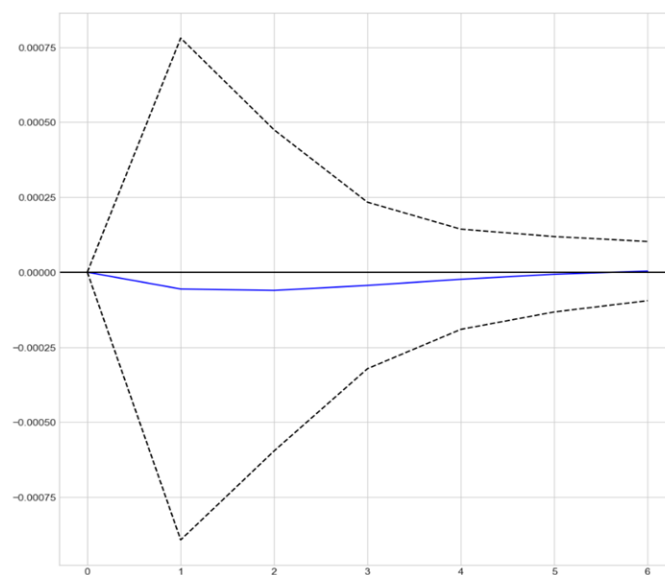


Figure 8. Loan delinquency in the wage index

IRF for population illustrates a stable negative reaction to rising loan defaults, which shows decreasing population salary and decreasing demand for the labor force after the tightening of credit conditions.

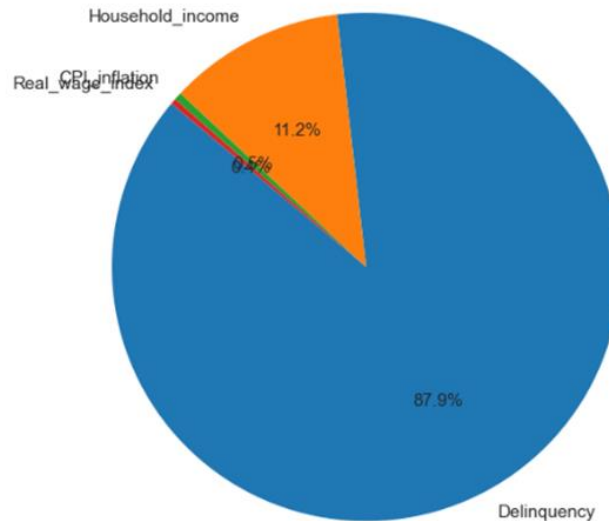


Figure 9. Variance decomposition of the forecast error (VED) of the variance of overdue debt explained by macroeconomic shocks

In this figure, the variance decomposition of forecast error (FEVD) is shown, which was taken based on vector autoregression (VAR), which shows the impact of each macroeconomic factor on the dispersion of loan delinquency in a six-month forecast.

Intelligent control and automation level

Forecast results of Bayes-Sarimax transfer into the intellectual level of control, which dynamically corrects risk thresholds and re-learning model in feedback mode.

This mechanism enables adaptive real-time decision-making through continuous model updating and feedback learning.



Figure 10. Updating the feedback model

This figure shows the cycle of automation of decision making: forming a forecast, rating risks, then the result of control, and finally actualisation of feedback.

Rating and diagnostics of the model

The forecasting performance of the hybrid model was evaluated using standard statistical accuracy metrics:

$$R^2 = 1 - \frac{\sum(Y_t - \hat{Y}_t)^2}{\sum(Y_t - \bar{Y})^2}, MAE = \frac{1}{n} \sum |Y_t - \hat{Y}_t|, MAPE = \frac{100}{n} \sum \left| \frac{Y_t - \hat{Y}_t}{Y_t} \right|$$

where: R^2 – coefficient of determination;

MAE – mean absolute error;

$MAPE$ – mean absolute percentage error;

Y_t – actual observed values at time t ;

$\hat{Y}_t$ – forecasted values generated by the model;

$\bar{Y}$ – mean value of observed data;

n – total number of observations.

Metrics are tested using the Durbin-Watson (autocorrelation) and Shapiro-Wilk (normality) test to be sure on correctness on statistical reliability.

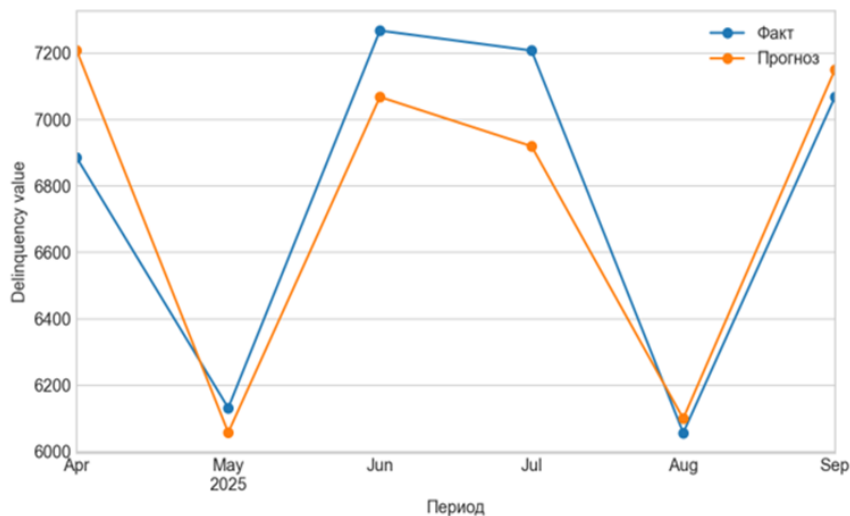


Figure 11. Actual and forecasted overdue debt (six-month forecast horizon)

In this figure, we compare the facts of observed indicators of delinquency with forecast indicators for the future into 6-month periods. The total coefficient of determination ($R^2=0.92$) shows proof of a high explanatory force, while narrow intervals of forecast show us that the Bayesian component effectively understands uncertainty. This visualization demonstrates the model's ability to provide reliable, interpretable predictions to automate decision-making in intelligent control systems.

Robustness under structural shocks

The robustness of the proposed hybrid model was additionally evaluated under periods of macroeconomic instability and structural fluctuations.

The Bayesian updating mechanism allowed the model to adapt to changes in macroeconomic conditions by dynamically revising parameter uncertainty.

Results demonstrated stable forecasting performance under inflationary shocks, changes in household income, and variations in credit market conditions.

RESULTS

Empirical realisation of the hybrid model: Bayes-Sarimax model shows us macrofinancial mechanisms, which define the dynamics of loan delinquency of the loan portfolio. In this section, quantitative results are presented, model diagnostics, and structure visualisation of relationships between variables.

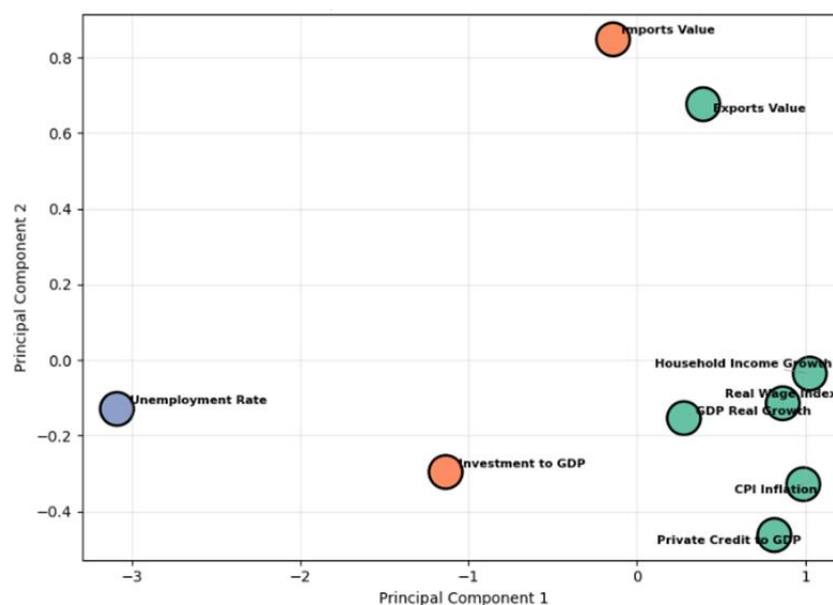


Figure 12. Clustered map of macroeconomic indicators (PCA-K Means)

This figure illustrates the relationship and group between macroeconomic factors that influence the dynamics of loan delinquency. By analyzing the main components and clusterization, K-means and 9 indicators were reduced to two composite dimensions:

Real sector(green cluster): Inflation CPI, index of Real Wage, increasing income, and rising GDP.

Financial sector(orange cluster): private credit to GDP and investment to GDP.

External sector/Labor sector(blue cluster): export, import, and unemployment rate.

The PCA card approves the risk of loan delinquency for the first time, influenced by stress in the real sector, and the secondary influence is the financial and external sectors. This structure provides the basis for the macrosensitivity forecast in the Bayes-Sarimax system.

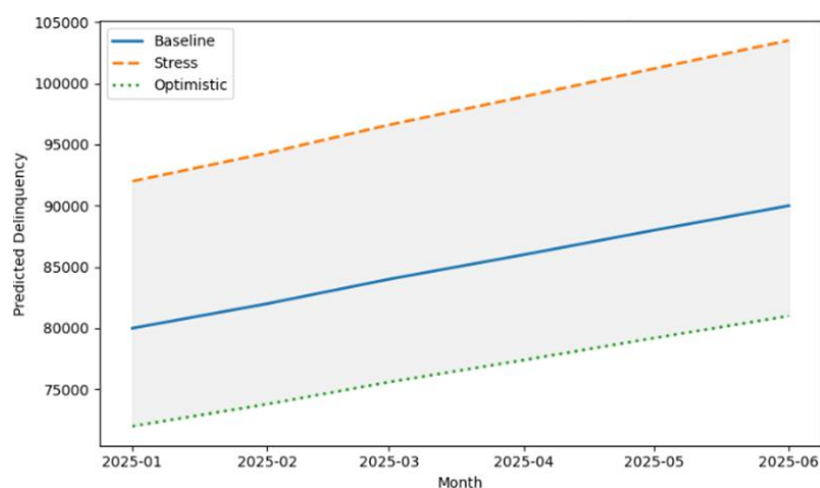


Figure 13. Actual and projected overdue debt

This visualisation compares forecast and fact metrics of checking periods, by demonstrating the accuracy for different periods. The hybrid model achieves a high value of R^2 and low metrics of MAE and MAPE, which support forecast reliability.

DISCUSSION

Results show that the hybrid model Bayes-Sarimax gives a flexible structure for forecasting, taking into account the intellectual automation of decision-making.

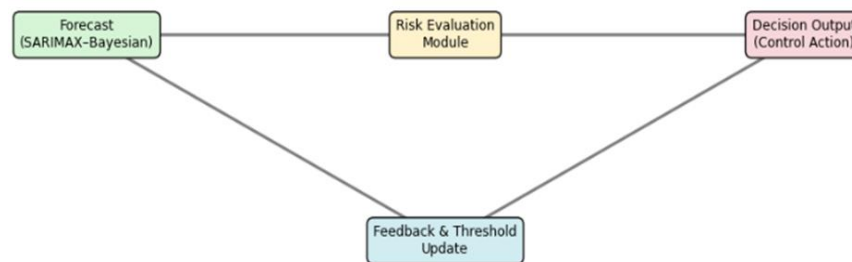


Figure 14. Intelligent decision feedback loop (connected and multi-level)

In this figure, the intellectual cycle of feedback is illustrated. mode for decision-making, which includes modules for forecasting, rating, and adaptive control.

- Forecasting Layers (Bayesian-Sarimax): Generate probabilistic forecasts of loan delinquency under macroeconomic uncertainty.
- Module of rating risks: quantitative rating approveness of portfolio and expected losses, provision of interpretade results.
- Decision Output(Control Action): using conditions of policy, like correction or credit tightening.
- Mechanism of feedback: trains the model by using the realized for providing self learning and continuous calibration. This method not only increases the stability and accuracy of the forecast but it also supports the control of macrorisks in financial organizations in real time.

CONCLUSIONS

The study showed that integration of the Bayes method with the Sarimax form is an effective basis for the intellectual automatization process of forecasting and controlling credit risks. The hybrid structure includes probability methods and dynamic modeling of time series, which simultaneously take into account macroeconomic relations and stochastic uncertainty. These methods provide a deeper understanding of the causal effects between the dynamics of crime, inflation, real income, rising GDP, and macrofinancial indicators by forming a transparent and explainable system of forecasting.

Intellectual contour of the feedback loop, which is realized through a hybrid system architecture that provides adaptive control, learning, and continuous calibration of the forecast. This structure corresponds to the principal intellectual system control, allowing the automation process of decision-making, saving transparency and explainability of models. As a result, the offer of the system of Bayesian SARIMAX can be used as a reliable tool for an adaptive platform of financial control, increasing the stability of credit organizations and improving the management of macroeconomic risks in uncertain conditions.

CONFLICTS OF INTEREST: The authors declare no conflict of interest.

FUNDING: This paper was written under grant AP19679142 “Search for optimal solutions in Bayesian networks in models with linear constraints and linear functionals. Development of algorithms and programs” (2023–2025) of the Ministry of Science and Higher Education of the Republic of Kazakhstan.

DATA AVAILABILITY STATEMENT: The data and computational code used in this study are available from the corresponding author upon reasonable request.

Due to banking data confidentiality, some raw financial datasets cannot be publicly shared, but all transformed data and modeling scripts are provided for replication.

REFERENCES

- Alharbi, F. R., & Csala, D. (2022). A seasonal autoregressive integrated moving average with exogenous factors (SARIMAX) forecasting model-based time series approach. *Inventions*, 7(4), Article 94. <https://doi.org/10.3390/inventions7040094>
- Asokan, R., Ruiz, D. P., & Piramuthu, S. (Eds.). (2024). *Smart data intelligence*. Springer. <https://doi.org/10.1007/978-981-97-3191-6>
- Au, J., Saldaña, J. J., Spanswick, B., & Santerre, J. (2022). Forecasting power consumption in Pennsylvania during the COVID-19 pandemic: A SARIMAX model with external COVID-19 and unemployment variables. *SMU Data Science Review*, 5(1), Article 14. <https://scholar.smu.edu>
- Banaś, J., & Utnik-Banaś, K. (2021). Evaluating a seasonal autoregressive moving average model with an exogenous variable for short-term timber price forecasting. *Forest Policy and Economics*, 131, Article 102564. <https://doi.org/10.1016/j.forpol.2021.102564>
- Döring, L., Grumbach, F., & Reusch, P. (2024). Optimizing sales forecasts through automated integration of market indicators. *arXiv*. <https://doi.org/10.48550/arXiv.2406.07564>
- Gruber, L., & Kastner, G. (2025). Forecasting macroeconomic data with Bayesian VARs: Sparse or dense? It depends! *International Journal of Forecasting*, 41(1), 1–24. <https://doi.org/10.1016/j.ijforecast.2025.02.001>
- Hasan, I., Horváth, R., & Mares, J. (2018). What type of finance matters for growth? Bayesian model averaging evidence. *World Bank*. <https://doi.org/10.1596/32782>
- Hossain, M. J. (2023). Comparative analysis of ARIMA, SARIMAX, and random forest models for forecasting future GDP of the UK in relation to unemployment rate. *Zenodo*. <https://doi.org/10.5281/zenodo.10473611>
- Kachalla, I. A., Ghiaus, C., Ademuwagun, A., Odeyinde, O. B., & Baseer, M. (2025). Data-driven hybrid SARIMAX-MLP framework for energy consumption prediction in residential micro-grid. *Results in Engineering*, 26, Article 105336. <https://doi.org/10.1016/j.rineng.2025.105336>
- Karim, A. A., Pardede, E., & Mann, S. (2023). A model selection approach for time series forecasting: Incorporating Google Trends data in Australian macro indicators. *Entropy*, 25(8), Article 1144. <https://doi.org/10.3390/e25081144>
- Lee, G.-C. (2025). A data-driven approach to tourism demand forecasting: Integrating web search data into a SARIMAX model. *Data*, 10(5), Article 73. <https://doi.org/10.3390/data10050073>
- Marcellino, M., & Pfarrhofer, M. (2024). Bayesian nonparametric methods for macroeconomic forecasting. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.4857173>
- Martin, G. M., Frazier, D. T., Maneesoonthorn, W., Loaiza-Maya, R., Huber, F., Koop, G., Maheu, J., Nibbering, D., & Panagiotelis, A. (2024). Bayesian forecasting in economics and finance: A modern review. *International Journal of Forecasting*, 40(3), 101–150. <https://doi.org/10.1016/j.ijforecast.2023.05.002>
- McAlinn, K., Aastveit, K. A., Nakajima, J., & West, M. (2020). Multivariate Bayesian predictive synthesis in macroeconomic forecasting. *Journal of the American Statistical Association*, 115(531), 1092–1105. <https://doi.org/10.1080/01621459.2019.1660171>
- Nishanthi, M., & Pandiyan, P. (2026). A Bayesian approach to SARIMAX-LSTM ensemble for solar energy prediction. In R. Asokan, D. P. Ruiz, & V. D. Păvăloaia (Eds.), *Smart data intelligence* (pp. 309–325). Springer. https://doi.org/10.1007/978-981-96-5265-5_24
- Satheesh, A., & Sundararagan, S. (2022). An analysis of the feasibility of SARIMAX-GARCH through load forecasting. *Journal of Emerging Investigators*, 5(11), Article 22-085. <https://doi.org/10.59720/22-085>

- Scott, S. L., & Varian, H. R. (2013). Bayesian variable selection for nowcasting economic time series (NBER Working Paper No. 19567). National Bureau of Economic Research. <https://doi.org/10.3386/w19567>
- Shah, V., Patel, N., Shah, D., Swain, D., Mohanty, M., Acharya, B., Gerogiannis, V. C., & Kanavos, A. (2024). Forecasting maximum temperature trends with SARIMAX: A case study from Ahmedabad, India. *Sustainability*, 16(16), Article 7183. <https://doi.org/10.3390/su16167183>
- Sznajderska, A., & Haug, A.A. (2023). Bayesian VARs of the U.S. economy before and during the pandemic. *Eurasian Economic Review*, 13(2), 229–255. <https://doi.org/10.1007/s40822-023-00229-9>
- Tham, A., Kakamu, K., & Liu, S. (2023). Bayesian statistics for loan default. *Journal of Risk and Financial Management*, 16(3), Article 203. <https://doi.org/10.3390/jrfm16030203>
- Traczynski, J. (2017). Firm default prediction: A Bayesian model-averaging approach. *Journal of Financial and Quantitative Analysis*, 52(3), 1211–1245. <https://doi.org/10.1017/S002210901700031X>
- van der Drift, R., de Haan, J., & Boelhouwer, P. (2024). Forecasting house prices through credit conditions: A Bayesian approach. *Computational Economics*, 63(4), Article 10542. <https://doi.org/10.1007/s10614-023-10542-9>

Авторлар туралы мәліметтер
Информация об авторах
Information about authors



Шаяхметова Әсем – PhD докторы, доцент, әл-Фараби атындағы Қазақ ұлттық университеті, Алматы қ., Қазақстан.

Шаяхметова Асем – доктор PhD, доцент, Казахский национальный университет имени аль-Фараби, г. Алматы, Казахстан.

Assem Shayakhmetova – PhD, Associate Professor, al-Farabi Kazakh National University, Almaty, Kazakhstan.

e-mail: shayakhmetova.assem@kaznu.kz

ORCID: <https://orcid.org/0000-0002-4072-3671>



Ахметова Ардак – PhD докторы, доцент, әл-Фараби атындағы Қазақ ұлттық университеті, Алматы қ., Қазақстан.

Ахметова Ардак – доктор PhD, доцент, Казахский национальный университет имени аль-Фараби, г. Алматы, Казахстан.

Ardak Akhmetova – PhD, Associate Professor, al-Farabi Kazakh National University, Almaty, Kazakhstan.

e-mail: akhmetova.ardak@kaznu.kz

ORCID: <https://orcid.org/0009-0000-2605-7206>



Абдурахманов Нуркен – PhD студент, әл-Фараби атындағы Қазақ ұлттық университеті, Алматы қ., Қазақстан.

Абдурахманов Нуркен – студент PhD, Казахский национальный университет имени аль-Фараби, г. Алматы, Казахстан.

Abdurakhmanov Nurken – PhD Student, al-Farabi Kazakh National University, Almaty, Kazakhstan.

e-mail: ngsn4246@gmail.com

ORCID: <https://orcid.org/0009-0009-8271-4106>