sciendo International Conference KNOWLEDGE-BASED ORGANIZATION
Vol. XXXI No 2 2025

NOMINAL CONVERGENCE OPTIMIZATION FOR ROMANIA'S EURO AREA ACCESSION: A LINEAR PROGRAMMING APPROACH

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Abstract: *This paper evaluates Romania's progress toward meeting the nominal convergence criteria required for Euro Area accession, employing a linear programming model over the period 2007–2024. The methodology is based on minimizing the weighted sum of absolute deviations from the Maastricht reference values for five key macroeconomic indicators: inflation rate, long-term interest rate, exchange rate volatility, budget deficit, and public debt. By assigning specific weights to each criterion and calculating annual deviation scores, the model offers a synthetic and quantifiable assessment of Romania's convergence trajectory. The results highlight 2012–2014 as the most favorable period, with minimal deviations and broad macroeconomic stability. In contrast, 2008–2009 and 2021–2022 emerge as periods of substantial misalignment, driven respectively by the global financial crisis and pandemic-related economic shocks. The findings underline inflation and fiscal deficit as the most critical barriers to convergence, while exchange rate volatility and public debt remained within manageable limits. The paper concludes that consistent convergence, rather than episodic compliance, is essential for sustainable Euro adoption, and that linear optimization provides a valuable tool for convergence diagnostics and policy evaluation.*

Keywords: nominal convergence, inflation, Euro, optimization, linear programming

1. Introduction: background and literature review

The adoption of the euro represents both a strategic objective and a significant macroeconomic challenge for EU Member States outside the Euro Area. For Romania, the euro accession process requires more than political commitment, it demands rigorous compliance with the Maastricht convergence criteria, which cover key indicators of nominal stability. These include price stability, sound public finances, exchange rate stability, and long-term interest rate convergence. Although Romania has formally committed to joining the Euro Area, repeated delays and inconsistent economic performance have raised questions about the country's readiness and the sustainability of its convergence trajectory.

The Maastricht Treaty (1992) sets out explicit nominal criteria for Euro Area entry, aimed at ensuring that adopting countries possess macroeconomic environments compatible with the requirements of a monetary union. Specifically, these include: an inflation rate no more than 1.5 percentage points above the average of the three best-performing EU Member States, a government budget deficit below 3% of GDP, public debt not exceeding 60% of GDP, exchange rate stability within the ERM II band for at least two years and long-term interest rates not

DOI: 10.2478/kbo-2025-0042

more than 2 percentage points above the reference countries. These indicators aim to promote stability and prevent asymmetric shocks in a currency union.

Romania's path toward nominal convergence has been uneven. While the country made notable progress in certain periods, especially during 2012–2014, when macroeconomic discipline and post-crisis adjustments led to favorable alignment with Maastricht indicators, other phases were characterized by inflation volatility, fiscal slippage or external shocks. The post-2020 period, marked by the COVID-19 pandemic [18], war in Ukraine and energy crises, has further complicated the economic context, making convergence more challenging.

Most analyses of convergence in the literature focus on descriptive comparisons, econometric models [15], or structural assessments of policy frameworks [17]. However, few studies have adopted a quantitative optimization approach to assess convergence performance over time. This paper seeks to fill that gap by applying linear programming, a method traditionally used in operations research and economics, to model Romania's annual deviations from the Maastricht reference values.

By doing so, the paper introduces an innovative tool for evaluating the extent and sustainability of nominal convergence. Instead of checking whether individual criteria are met in isolation, the linear programming model aggregates deviations across all indicators into a single objective function, allowing for a synthetic assessment of each year's macroeconomic alignment. This approach not only quantifies how far Romania is from full compliance but also identifies the most influential variables driving divergence.

The question of nominal convergence has been widely addressed in the academic literature, particularly in the context of EU enlargement [4] and the functioning of the Economic and Monetary Union (EMU) [2], [5, 12]. Early works [6, 8, 14] emphasized the importance of sustainable convergence and the risks of premature euro adoption. More recent studies [10, 13], analyzed the Central and Eastern European (CEE) countries' trajectories toward the euro, warning of the structural gaps and macroeconomic instability [7] that could undermine successful accession. In Romania's context, Ailincăi [1] highlighted the tension between fast convergence and macroeconomic prudence, arguing that achieving nominal convergence in a sustainable manner requires strong institutional frameworks and disciplined fiscal policies. Slunjski & Dumanči [21] applied econometric analysis to assess Romania's compliance with Maastricht criteria and concluded that while public debt and interest rates showed positive trends, inflation and fiscal balance remained problematic. In the context of Romania's euro adoption strategy, recent research has emphasized the need for a comprehensive assessment of convergence indicators beyond mere threshold compliance. Schipor and Duhnea [19] conducted an in-depth evaluation of Romania's nominal convergence performance, highlighting both the periods of alignment with the Maastricht criteria and the recurring structural deviations that hinder long-term compliance. Their findings underscore the importance of adopting a more integrated and dynamic framework for assessing convergence readiness. Complementing this perspective, Tita et al. [22] argue that the sustainability of public finances, particularly through a credible medium-term budgetary framework, is essential for reinforcing macroeconomic stability and achieving durable convergence. However, most of these studies rely on point-in-time assessments or trend-based forecasts [3], [16]. There is limited research that incorporates optimization techniques to evaluate convergence pathways over time. Górna et al. [11] introduced a composite index to measure convergence, but did not explore how various indicators interact

within a constrained optimization framework.

Linear programming, although extensively used in production planning, resource allocation, and logistics, has been increasingly applied in economic policy modeling, particularly in areas such as public finance, investment strategies, and macroeconomic balance (e.g. [9, 20]). Its application to nominal convergence is novel and offers a structured way to prioritize macroeconomic reforms based on quantitative deviations from policy targets.

This paper builds upon these foundations by applying LP to Romania's macroeconomic data from 2007 to 2024, calculating annual objective scores and identifying the periods of closest alignment and greatest deviation from the Maastricht reference points.

The content of the paper is structured as follows: Section 2 presents the methodology, including the formulation of the linear programming model and the data sources. Section 3 displays the empirical results, including the evolution of convergence scores and a discussion of the best and worst performing years. Finally, Section 4 provides a policy-oriented interpretation of the results, offering concrete recommendations for achieving sustainable convergence, along with implications for Romania's euro adoption strategy and suggestions for future research directions.

2. Research methodology

Linear programming is a mathematical optimization technique used to identify the best possible outcome, such as maximum profit or minimum cost, within a given set of constraints. In this paper, linear programming is applied to **minimize the total deviation** of Romania's economic indicators from the reference values set by the Maastricht Treaty, which define the eligibility conditions for Euro Area entry. The purpose is to develop a quantitative model that captures the extent of deviation from the Maastricht criteria across five key economic indicators. Rather than assessing each criterion in isolation, the proposed method calculates a weighted, aggregated deviation score for each year in the analysis period (2007–2024), thereby allowing for both cross-indicator and intertemporal comparisons.

Traditional analyses of nominal convergence often use threshold comparisons or econometric models that predict whether criteria will be met. In contrast, the linear programming approach enables a structured, multi-indicator optimization of convergence performance by incorporating variable weighting, explicit constraints and a unified objective function.

2.1. Model Formulation

The linear programming problem is formulated as follows:

Components of a linear programming problem:

$$\begin{aligned} &\min(\max)\ z = c_1x_1 + c_2x_2 + ... + c_nx_n \\ &\begin{cases} a_{11}x_1 + a_{12}x_2 + ... + a_{1n}x_n < b_1 \\ a_{21}x_1 + a_{22}x_2 + ... + a_{2n}x_n < b_2 \\ ..... \\ a_{m1}x_1 + a_{m2}x_2 + ... + a_{mn}x_n < b_m \end{cases} \\ &x_1 + x_2 + ... + x_n > 0 \end{aligned} \quad (1)$$

where:

- x - decision variables (number of product goods or resources allocated for the given solution).
- c - contribution coefficient (how much each good or resource contributes to the given solution).
- z - unknown function (usually an expression of the combined resources needed to provide the optimal solution).
- b - secondary constraints (usually mathematical expressions of resource limitations, however they can represent virtually any limiting factors that can be

expressed as linear mathematical functions).

- *a* - amount of the resource needed to produce the number *x*.

To carry out the convergence analysis, we considered five key macroeconomic indicators directly associated with the Maastricht nominal convergence criteria: the inflation rate, long-term interest rate, exchange rate volatility, budget deficit, and public debt. These indicators were collected annually for the period 2007–2024, encompassing both periods of economic growth and episodes of macroeconomic instability. The evolution of these indicators over time provides the empirical foundation for the optimization model and allows for a comparative analysis of Romania's progress toward fulfilling the euro adoption requirements. A detailed presentation of the annual values for each indicator is provided in **Annex 1** - Key macroeconomic indicators relevant for nominal convergence in Romania (2007–2024). These variables correspond to the components of the objective function aimed at minimizing the total weighted deviation from the Maastricht reference values, as follows:

- x_1 - inflation rate;
- x_2 - long-term interest;
- x_3 - exchange rate (volatility);
- x_4 - budget deficit;
- x_5 - public debt.

The corresponding Maastricht reference values are presented in Table 1.

Table 1 Maastricht reference values

Indicator	**Notation** r_i
Inflation	2.5%
Interest	5%
Exchange rate	0%
Budget deficit	-3%
Public debt	60%

Each indicator is assigned a weight (w_i) to reflect its relative importance in the convergence assessment. The weights are based on both theoretical relevance (as inferred from EU convergence criteria) and the economic impact of the respective indicators on macroeconomic stability.

Table 2 -Weighting scheme for nominal convergence indicators in the optimization model

Indicator	**Value**
Inflation	0.25
Interest	0.2
Exchange rate	0.15
Budget deficit	0.25
Public debt	0.15

The sum of weights equals 1.00, ensuring a balanced and interpretable optimization outcome.

The objective function will be :

Minimum

Z= $w_1 d_1 + w_2 d_2 + w_3 d_3 + w_4 d_4 + w_5 d_5$,

Where:

$-d_1, d_2, d_3, d_4, d_5$ - absolute deviations from reference values.

namely:

Minimum

Z=

$0.25 d_1 + 0.2 d_2 + 0.15 d_3 + 0.25 d_4 + 0.15 d_5$

where $d_i \geq |x_i - r_i| \Rightarrow \begin{cases} d_i \geq x_i - r_i \\ d_i \geq r_i - x_i \end{cases}$.

For each indicator we compute the absolute deviation and find the minimum.

We have some additional constraints:

$$\begin{cases} x_1 < 1.5\% \\ x_2 < 2\% \\ x_3 \in [-15\%, 15\%], \\ x_4 < 3\% \\ x_5 < 60\% \end{cases}$$

So we obtain some new constraints for the absolute deviations:

$$\begin{cases} d_1 > 1 \\ d_2 > 3 \\ d_3 > 15 \\ d_4 \geq 0 \\ d_5 > 0 \end{cases}$$

To solve the formulated linear programming problem, the LINDO optimization software was used, given its capacity to handle structured models with multiple variables and constraints efficiently.

The model was initially applied to the data corresponding to the year 2007, as a representative example of the implementation process. LINDO generated the optimal solution by minimizing the weighted sum of absolute deviations from the Maastricht reference values, using the constraints defined for each deviation variable. The solution output is presented in Figure 1, which illustrates the structure and result of the objective function at optimum.

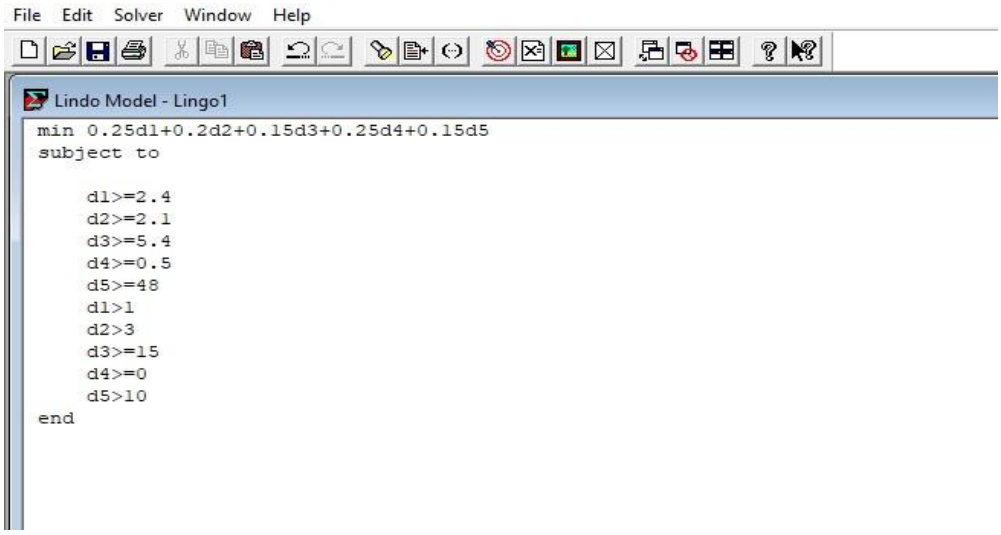
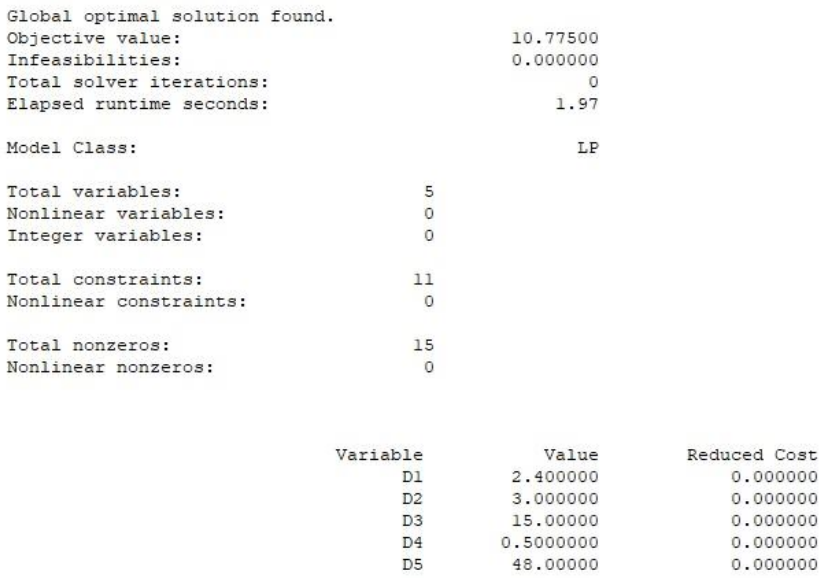


Figure 1: LINDO Optimum (Author's compilation)

Additionally, Figure 2 provides the detailed LINDO output, confirming the values assigned to each deviation variable and verifying the compliance with all imposed constraints.



```
Global optimal solution found.
Objective value:                              10.77500
Infeasibilities:                              0.000000
Total solver iterations:                             0
Elapsed runtime seconds:                          1.97

Model Class:                                        LP

Total variables:                     5
Nonlinear variables:                 0
Integer variables:                   0

Total constraints:                  11
Nonlinear constraints:               0

Total nonzeros:                     15
Nonlinear nonzeros:                  0


                   Variable           Value        Reduced Cost
                         D1        2.400000            0.000000
                         D2        3.000000            0.000000
                         D3        15.00000            0.000000
                         D4       0.5000000            0.000000
                         D5        48.00000            0.000000
```

Figure 2: LINDO solution for Optimum (Author's compilation)

These figures demonstrate the applicability of linear optimization in assessing nominal convergence performance and validate the consistency of the model across annual scenarios.

The results obtained from applying the linear programming model are summarized in in **Annex 2**, which presents the annual absolute deviations from the Maastricht reference values for each of the five nominal convergence indicators, as well as the corresponding value of the objective function. A lower score indicates a closer approximation to the Maastricht thresholds.

3. Results and discussions

The linear optimization model applied to Romania's nominal convergence criteria over the period 2007–2024 offers insightful conclusions regarding the country's readiness for Euro Area accession. The objective function, designed to minimize the weighted sum of absolute deviations from the Maastricht reference values, acts as a synthetic indicator of compliance.

The analysis of the evolution of the objective function over the 2007–2024 period reveals notable fluctuations in Romania's progress toward nominal convergence. Between 2010 and 2014, Romania experienced a phase of steady improvement, marked by decreasing values of the objective function. This period coincided with the country's post-crisis macroeconomic stabilization, characterized by disciplined fiscal policy, low inflation, and decreasing public debt. In 2014, the objective function reached its lowest value (Z = 6.42), indicating the closest alignment with the Maastricht criteria during the entire period analyzed.

Following this interval of relative convergence, the scores began to rise again, especially after 2015, reflecting renewed macroeconomic imbalances. This upward trend in the objective function values during 2016–2019 suggests that while some indicators remained within acceptable limits (notably public debt and interest rates), inflation and budget deficit volatility prevented full compliance. The convergence path deteriorated further in 2020–2022, driven by the fiscal and monetary shocks caused by the COVID-19 pandemic and subsequent global inflationary pressures. The highest value in the post-pandemic years was recorded in 2022 (Z = 8.73), driven by an inflation macroeconomic rebalancing with an improved score (Z = 6.45), this level

remains slightly above the optimal period of 2012–2014, highlighting the incomplete recovery of convergence performance.

Among the five Maastricht-related indicators incorporated into the optimization model, inflation emerges as the most volatile and disruptive component. In several years, especially 2008, 2021, and 2022, the inflation rate's deviation from the reference value (2.5%) significantly increased the total score. For instance, in 2022, the deviation from the inflation benchmark was 13.8 points, contributing disproportionately to the overall objective function value. This demonstrates that even moderate alignment in the other four indicators cannot compensate for the macroeconomic instability induced by inflationary shocks.

The budget deficit also plays a central role in determining the convergence score. Romania consistently failed to meet the -3% ceiling in the post-2020 period. The fiscal expansion during the COVID-19 crisis and the subsequent increase in social and public sector expenditures led to high deficits of -6.8% in 2021 and -6.9% in 2024. Even in years of relatively good inflation performance (e.g. 2013–2014), the inability to maintain sustained fiscal consolidation remained a vulnerability.

By contrast, public debt remained consistently below the Maastricht threshold of 60% of GDP, even during crisis years. However, the upward trajectory observed since 2018 and the crossing of the 50% threshold by 2021 signals growing long-term sustainability concerns. Lastly, exchange rate volatility remained well-controlled after 2013, contributing positively to the convergence profile. The successful management of Romania's controlled float exchange rate regime helped keep this variable close to the reference point, thereby lowering its contribution to the total deviation score.

The model identifies the years 2012 to 2014 as the most favorable period for Romania in terms of nominal convergence. In 2014, the objective function reached its historical minimum (Z = 6.42), followed closely by 2012 (Z = 6.56) and 2013 (Z = 6.63). During this period, macroeconomic management was oriented toward compliance with European fiscal rules and inflation was kept under control. These years also witnessed a sustained improvement in public debt ratios and relatively stable interest rates.

The success of this period is attributable to prudent fiscal adjustments following the global financial crisis and Romania's commitment to structural reform under EU supervision. Importantly, all key indicators, except for exchange rate volatility, showed deviations well within tolerable limits. The model confirms that this interval represents the most sustained effort toward Euro Area readiness since Romania's EU accession.

In contrast, the worst convergence scores were recorded during systemic shocks. In 2008 and 2009, Romania faced the global financial crisis, which translated into high inflation, interest rate spikes, and a rapidly growing public debt. The optimization model assigns a score of 11.92 to 2008 and 11.02 to 2009, the highest of the entire series. These results confirm that external shocks, when coupled with weak domestic policy coordination, severely compromise convergence prospects. More recently, 2022 stands out as a new peak in deviation (Z = 8.73), driven primarily by the inflationary surge triggered by post-pandemic global supply shocks and the energy crisis. The budget deficit and public debt, although stabilized somewhat compared to 2009, remained above desirable thresholds. This suggests that structural resilience has improved since the 2008 crisis, but macro-financial fragility remains, particularly under inflationary pressure.

4. Conclusions

This study applied a linear programming approach to evaluate Romania's progress

toward nominal convergence with the Maastricht criteria over the 2007–2024 period. By minimizing the weighted sum of absolute deviations from the reference values across five key macroeconomic indicators, the model offered a synthetic, quantitative measure of Romania's readiness for Euro Area accession. The results indicate significant variability in convergence performance across the analyzed period, with 2012–2014 emerging as the most favorable years, and 2008–2009 and 2021–2022 reflecting the most substantial misalignments.

From a policy perspective, the findings highlight two major areas of concern: persistent inflation volatility and structural fiscal imbalances. While Romania has maintained public debt levels below the Maastricht ceiling and has ensured relative exchange rate stability, episodes of fiscal expansion and inflationary surges have consistently undermined nominal convergence. These vulnerabilities were particularly evident in the aftermath of global shocks such as the 2008 financial crisis and the COVID-19 pandemic, underscoring the importance of macroeconomic resilience and sound policy frameworks.

To achieve sustainable convergence, Romanian policymakers should prioritize the following:

- ✓ strengthening the credibility and effectiveness of inflation-targeting mechanisms,
- ✓ implementing medium-term fiscal consolidation strategies anchored in realistic macroeconomic assumptions
- ✓ improving the structural balance of public finances to reduce reliance on pro-cyclical spending.

A forward-looking policy mix should also aim to enhance institutional quality and policy coordination, particularly in areas that influence convergence-sensitive indicators.

In terms of euro adoption, the results suggest that Romania's path remains viable but contingent on sustained macroeconomic discipline. Nominal convergence should not be viewed as a temporary or static condition, but as a dynamic process that requires consistent adherence to stability-oriented policies. While occasional compliance with Maastricht thresholds may offer short-term eligibility, the long-term success of euro adoption depends on a credible track record of convergence supported by robust economic fundamentals.

Finally, the study opens several avenues for future research. The linear programming model could be extended to incorporate real convergence indicators (e.g., GDP per capita, productivity) or to simulate policy scenarios under different weighting structures. Additionally, applying the model to other EU Member States outside the Euro Area could offer comparative insights and enrich the broader literature on convergence assessment. Integrating stochastic elements or sensitivity analysis could further enhance the model's robustness and policy relevance.

The findings form this paper demonstrates that linear programming offers a valuable and adaptable tool for assessing convergence performance, bridging the gap between theoretical criteria and empirical policy evaluation. Its application to Romania's case contributes to a deeper understanding of the country's progress toward Euro Area integration and the reforms required to achieve sustainable nominal stability.

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Annex no. 1 Key macroeconomic indicators relevant for nominal convergence in Romania (2007–2024).

Year	Inflation rate	Interest TL	Volatility price	Budget deficit	Public debt
2007	4.9	7.1	5.4	-2.5	12
2008	7.8	7.7	9.7	-5.4	12.4
2009	5.6	9.7	-15.1	-8.3	21.9
2010	5.5	7.6	-14.3	-7.2	29.8
2011	5.8	7.3	-0.6	-5.2	34.2
2012	3.4	6.7	-5.2	-3	37
2013	3.2	5.4	0.9	-2.3	37.6
2014	2.5	5.3	-1.9	-2.2	39.2
2015	-0.4	2.7	0	-0.7	37.8
2016	-1.1	3.3	-1	-3	37.3
2017	1.1	4	-1.7	-2.9	35.2
2018	1.9	4.1	-1.9	-3.3	34.1
2019	3	4.2	-0.4	-3.4	35.9
2020	3.1		0.8	-4.7	38.2
2021	8.19	4.8	1	-6.8	48.2
2022	16.3	7.7	1.2	-6.3	49.3
2023	10.4	6.2	0.8	-6.6	48.5
2024	7	5.5	0.5	-6.9	50

(Source: *Maastricht Treaty*)

Annex no. 2 - Annual absolute deviations from Maastricht reference values and optimization scores for Romania (2007–2024)

Year	d_1	d_3	d_4	d_5	Objective function
2007	2.4	5.4	0.5	48	10.775
2008	5.3	9.7	2.4	47.6	11.915
2009	3.1	15.1	5.3	38.1	11.020
2010	3	14.3	4.2	30.2	9.180
2011	3.3	0.6	2.2	25.8	8.095
2012	0.9	5.2	0	23	6.555
2013	0.7	0.9	0.7	22.4	6.635
2014	0	1.9	0.8	20.8	6.420
2015	2.9	0	2.3	22.2	7.480
2016	3.6	1	0	22.7	7.155
2017	1.4	1.7	0.1	24.8	6.945
2018	0.6	1.9	0.3	25.9	7.060
2019	0.5	0.4	0.4	24.1	6.815
2020	0.6	0.8	1.7	21.8	7.195
2021	5.69	1	3.8	11.8	6.992
2022	13.8	1.2	3.3	10.7	8.730
2023	7.9	0.8	3.6	11.5	7.450
2024	4.5	0.5	3.9	10	6.450

(Author's compilation using LINDO)