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Faculty of Economics and Administration

Department of System Engineering and Informatics

Using AHP and ANP in Public Administration

A case study of the euro convergence criteria

Master's Thesis

2021 Andrew Raykowski

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Theses guidelines

The objective of the thesis is to design a case study of the use of 'Analytic Hierarchy Process' (AHP) and 'Analytic Network Process' (ANP) in Public Administration. AHP and ANP algorithms are realized in software specified by the student.

The thesis will contain:

— introduction to multiple-criteria decision making

— description of AHP and ANP

— suggestion of a case study

— design of algorithms based on AHP and ANP for the case study

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Abstract

An overview of multiple-criteria decision-making systems, focusing on the Analytic Hierarchy Process and Analytic Network Process, is provided. An algorithm for applying these methods to a case study of the euro convergence criteria (Maastricht criteria), with eurozone candidate countries compared as alternatives, is then developed. Testing the algorithm on historical data produces several results showing close parallels to actual country join dates.

Keywords

MCDM, AHP, ANP, euro, convergence criteria, Maastricht criteria

Název

Využití AHP a ANP ve veřejné správě: Případová studie kritérií konvergence eura

Anotace

Je uveden přehled vícekriteriálních rozhodovacích systémů se zaměřením na proces analytické hierarchie a proces analytické sítě. Poté je vyvinut algoritmus pro aplikaci těchto metod na případovou studii kritérií konvergence eura (maastrichtských kritérií), přičemž kandidátské země eurozóny jsou srovnávány jako alternativy. Testování algoritmu na historických datech přináší několik výsledků ukazujících blízké paralely se skutečnými daty připojení zemí.

Klíčová slova

MCDM, AHP, ANP, euro, konvergenční kritéria, maastrichtská kritéria

CONTENT

LIST OF ILLUSTRATIONS AND TABLES

List of abbreviations and symbols except country codes

A	Alternative
AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
C	Criterion
CI	Calculated consistency index
CR	Consistency ratio
EC	European Commission
ECB	European Central Bank
ERM	European Exchange Rate Mechanism
EU	European Union
Geomean	Geometric mean
MCDM	Multiple-criteria decision making
n	Matrix size
p	Preferences
RI	Random consistency index
SC	Software comparison
λ_{max}	Maximum eigenvalue
σ	Standard deviation

List of country codes

BG	Bulgaria
CY	Cyprus
CZ	Czechia
EE	Estonia
HR	Croatia
HU	Hungary
LT	Lithuania
LV	Latvia
MT	Malta
PL	Poland
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia

INTRODUCTION

Decision-making is a critical part of both entire systems and individual activities. The decision maker often finds that in choosing between options, or alternatives, there are multiple parameters, or criteria, to be assessed and optimized. Thus, a problem arises: how to strategize the optimization of competing interests in the decision process to arrive at a single outcome.

Formally, this question belongs to the area of multiple-criteria decision making, and the systems that attempt to solve it using structured approaches are correspondingly termed multiple-criteria decision-making systems. One of the most frequently used of these systems is the Analytic Hierarchy Process, along with the closely related Analytic Network Process.

Given the broad nature of decision-making with multiple criteria, applications can be found in countless fields. Thus, it is instructive to see how such a system functions with arbitrary data from a chosen subject area. Doing so requires proposing a method of transforming the data into that expected by the specific multiple-criteria decision-making system.

The aim of the thesis is to describe multiple-criteria decision making in general and the Analytic Hierarchy Process in particular, followed by designing and testing an algorithm for applying this system to a case study in the field of public administration.

1 MULTIPLE-CRITERIA DECISION MAKING

Multiple-criteria decision making (MCDM) is a ubiquitous process used throughout numerous fields which has seen increased uptake in scholarly literature in recent years. [1] Unlike single-criteria decision making, which only depends on a single factor, the multiple-criteria methodology allows the decision maker to capture the real-world complexity of interrelated factors and model them to produce more reliable outcomes. Awareness of multiple-criteria decision making as a field, and especially the acronym MCDM, is often primarily attributed to a seminal paper on the topic that described the unfamiliarity and resultant lack of use of the methodology in applied settings. [2]

Largely due to its generic nature and consequent wide applicability, multiple-criteria decision making depends on the preferences of the decision maker even in terms of the choice of method itself. Hence a large variety of approaches to the concept exists, and new MCDM tools continue to be developed – both essentially novel ones, and enhancements of existing techniques. Figure 1 shows an example of the Analytic Hierarchy Process (AHP), one of the most widely used multiple-criteria decision-making systems and the focus of study here.

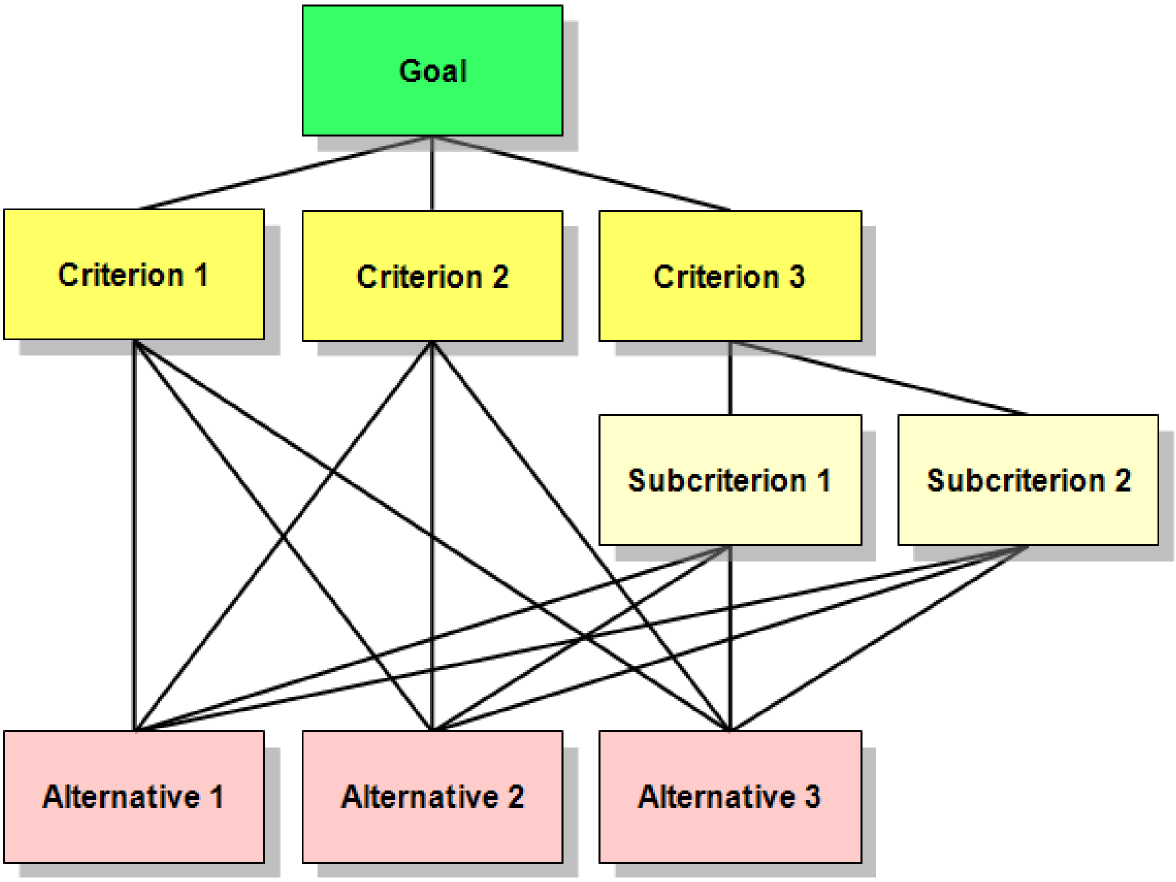

Figure 1: An Analytic Hierarchy Process (AHP) decision system with subcriteria

Source: [3]

The fundamental structure of multiple-criteria decision making generally consists of three layers: goals (a single goal in many MCDM applications), criteria, and alternatives. For each goal, the chosen MCDM system ranks the alternatives by the criteria based on the relative weights of the criteria and values for each alternative entered by the decision maker. Table 1 shows an empty decision table with alternatives A and criteria C, and rankings and weights.

Table 1: An empty decision table

		Ranking 1	…	Ranking n
		A_1	…	A_n
Weight 1	C_1		…	
…	…	…	…	…
Weight n	C_n		…	

Source: Adapted from [4, p. 4]

Criteria used can be of various types, such as quantitative or qualitative. [1, p. 517] Criteria can differ in their optimization nature: maximization, minimization, achievement of specific values, and so forth. In case of subcriteria, one or more additional MCDM levels can be added to the basic three.

Key differences between multiple-criteria decision-making approaches include how the weights are entered into the system, and how the overall weighting is calculated from the raw values given. It is therefore instructive to compare several MCDM approaches in this regard.

1.1 Criteria weighting

Perhaps the simplest decision-making weighting approach is the order method, shown in Table 2. Each criterion is assigned a consecutive integer value in order of importance, typically starting from 1 in denoting the least important element, then divided by the total. [5, p. 2] Its simplicity belies the robustness of the system, as it is a purely ordinal scale and therefore no information about relative preference distances is incorporated into the model.

Table 2: An example of the order weighting method

Criterion	C_1	C_2	C_3	C_4	C_5	**Total**
Value	5	4	3	2	1	**15**
Weight	0.333	0.267	0.2	0.133	0.067	**1**

Source: Author example

Another straightforward approach to MCDM weighting is using a point scale, as seen in Table 3. Instead of ordinal assessments, point scales provide more fine-grained information about criteria evaluation. Each criterion receives points on a scale, generally from 1 to a convenient value such as 5 or 9, or even 100. As with the order method, the lowest value of 1 is generally used for the least important factor, and each value is divided by the total. [5, p. 3]

Table 3: An example of the point scale weighting method

Criterion	C_1	C_2	C_3	C_4	C_5	**Total**
Value	9	7	5	3	1	**25**
Weight	0.36	0.28	0.2	0.12	0.04	**1**

Source: Author example

As shown in Table 4, points for multiple-criteria decision making can also be allocated out of a fixed value for the total number of points. Using 100 for the total value allows for direct interpretation of criteria weighs as percentages.

Table 4: An example of the point allocation weighting method

Criterion	C_1	C_2	C_3	C_4	C_5	**Total**
Value	36	28	20	12	4	**100**
Weight	0.36	0.28	0.2	0.12	0.04	**1**

Source: Author example

All three of these methods use very similar, simplistic tables to allocate values on a scale and convert them to weights out of 1. In practice, more robust techniques with pairwise comparison are employed.

1.2 Pairwise comparison

As with the basic methods, it is instructive to examine what is likely the simplest approach to pairwise comparison before proceeding with more advanced techniques. Unlike those previously discussed, however, the "Fuller method" of pairwise comparison is more suitable for practical use, when more detailed input is not required. An example is provided in Table 5.

Table 5: An example of a pairwise comparison using a Fuller triangle

C_n	C_1	C_2	C_3	C_4	C_5	p_1	p_0	p_1+p_0	p_1+p_0+1	**Weights**
C_1		1	1	1	1	4	0	4	5	**0.333**
C_2			1	1	1	3	0	3	4	**0.267**
C_3				1	1	2	0	2	3	**0.2**
C_4					1	1	0	1	2	**0.133**
C_5						0	0	0	1	**0.067**

Source: Author example

This approach works by arranging values in a square table, with both rows and columns corresponding to the factors being compared. For each pair of factors, a single value is entered in the table: 1 if the row factor is more important than the column one, or 0 if vice versa. In case of equally important factors, 0.5 can be entered, but this is more rarely used. As each pair appears twice in the table, and the diagonal with the same factors is not utilized, less than half of the table – generally the upper-right portion – is filled out. In accordance with this layout, the table is referred to as a "Fuller triangle". [5, p. 3]

For each factor, the calculation of weights proceeds by adding the number of "1" values in the corresponding row (p_1) to the number of "0" values in the respective column (p_0). This yields the total preferences for each factor. However, these are raw or unadjusted preferences, because the lowest-ranked factor has a weight of 0. Left unadjusted, this factor would be removed from the problem entirely – generally an undesirable outcome. The method instead uses adjusted preferences, which simply add 1 to each calculated value. The adjusted preferences are then divided by their total to obtain standardized, or normalized, weights out of 1. It is important to note that this adjustment is only performed for criteria assessment and is not used in alternative evaluation tables, where 0 weights are considered acceptable.

1.3 Alternative evaluation

Having selected a multiple-criteria decision-making weighting method, the next step is to apply it to both all the criteria together, and all the alternatives together for each criterion – as shown in Table 6. There should therefore be one more table than the number of criteria in total. As previously mentioned, the Fuller triangle is slightly different from that used for criteria assessment in that the values are not adjusted by adding 1.

Table 6: An example of Fuller method alternative evaluation

C_i	A_1	A_2	A_3	p_1	p_0	p_1+p_0	**Weights**
A_1		0	0	0	0	0	**0**
A_2			0	0	1	1	**0.333**
A_3				0	2	2	**0.667**

Source: Author example

As seen in Table 7, the final stage is to evaluate the alternatives, producing overall weights from the decision system. For each alternative, an overall weight is generated by multiplying the outcome for that alternative in each individual criterion table by the weight of that criterion from the table of criteria, and then adding all these products together. Regardless of method used, the total weight of all alternatives considering all criteria should add up to 1.

Table 7: Partial results based on the single evaluated criterion and equivalent full results

A_n	**Partial results (one criterion)**	**Equivalent full result values**
A_1	0	0
A_2	0.111	0.333
A_3	0.222	0.667

Source: Author example

1.4 MCDM in the literature

A wide variety of complex multiple-criteria decision-making approaches is employed in the literature. Four sources – the first two journal articles, the latter two published books – discussing a significant number of methods used have been selected for comparison. Table 8 provides a comparison from each literature source of the tools discussed in at least two of the four sources, yielding a list of 10 methods in total. Notably, only two of these methods are the subject of discussion in all four examined sources, including the primary focus here – AHP.

Table 8: Multiple-criteria decision-making methods in the literature

Method	**Acronym**	[6]	[7]	[8]	[9]
Analytic Hierarchy Process	AHP	✓	✓	✓	✓
Analytic Network Process	ANP	✓		✓	✓
Data Envelopment Analysis	DEA	✓	✓	✓	
Elimination and Choice Translating Reality	ELECTRE	✓	✓	✓	✓
Goal Programming	GP	✓	✓	✓	
Grey Theory/Gray Relational Model	(none)	✓			✓
Multi-Attribute Utility Theory	MAUT		✓	✓	
Preference Ranking Organization Method for Enriched Evaluation	PROMETHEE		✓	✓	✓
Simple Additive Weighting	SAW		✓		✓
Technique for Order of Preference by Similarity to Ideal Solution	TOPSIS		✓	✓	✓

Sources: [6], [7], [8], [9]

2 AHP AND ANP

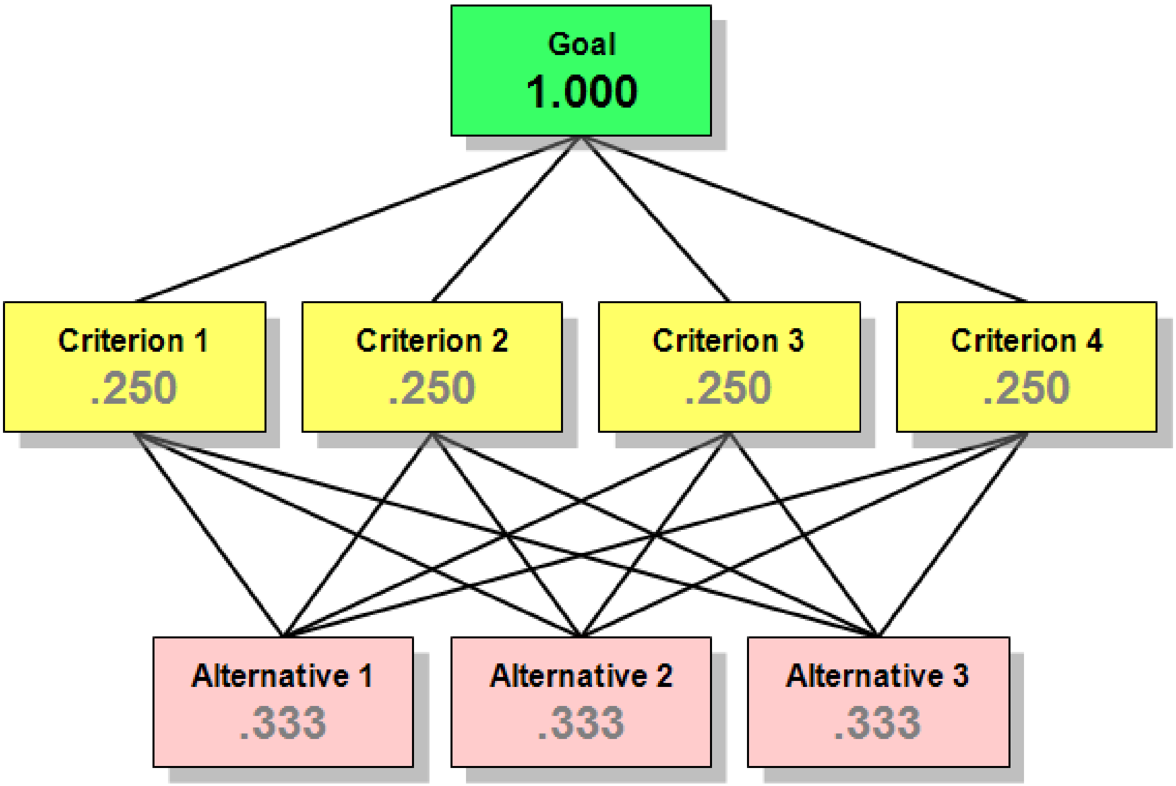

Figure 2: The fundamental structure of AHP with default priorities

Source: [3]

The Analytic Hierarchy Process describes an overall system of multiple-criteria decision making, which is generally based on the Saaty matrix for calculations. As the name indicates, it involves a structured hierarchy of goals, criteria, and alternatives. AHP is one of the most-used methods for MCDM [1, p. 524] and is implemented in numerous software packages.

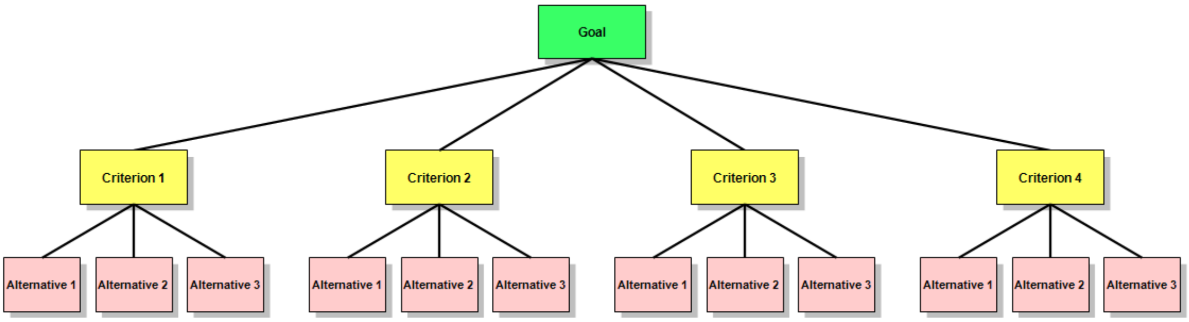

Figure 3: An expanded visualization of the AHP system

Source: [3]

Figure 2 shows the fundamental structure of AHP, with default priorities at each level adding up to 1. In Figure 3, the same system in seen in an expanded view, with more distinct connections. Finally, Figure 4 is an incomplete AHP diagram focused on the subcriteria level.

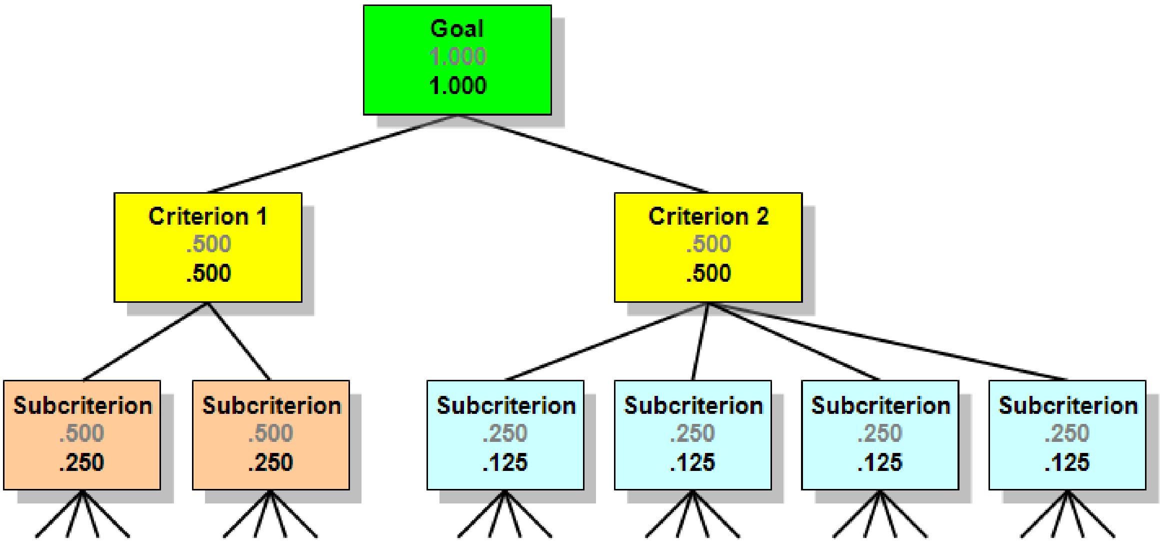

Figure 4: An AHP hierarchy with default local and global subcriteria priorities

Source: [3]

The Analytic Network Process (ANP) is a generalized version of AHP. It allows for both inner dependence, that within a set of elements, and outer dependence, among different sets of elements. ANP is therefore generally a nonlinear process, with AHP as a special linear case. [10, p. 2]

2.1 Criteria weighting

The Saaty method – named after Dr. Thomas L. Saaty (1926 – 2017), the creator of the AHP and ANP methods which use this procedure – is fundamentally like the Fuller one in that it also uses a square table of factors. However, instead of binary values, a Saaty table contains more fine-grained entries on a scale of 1 to 9. [11, p. 86] Generally, the main values used are the odd numbers in this interval, while the even integers can be employed if even greater precision is desired.

As with the Fuller method, only less than half of the table is filled in with unique values. However, whereas the Fuller triangle leaves the rest of the table blank, the Saaty table fills in the diagonal with the same factors with the value 1, and the remaining portion with reciprocals of the mirrored entries across the diagonal. [11, p. 85] As a result of the arrangement of the matrix, the most important criterion should only have integers in its row, and the least important only integers in its column.

Table 9: An example of a Saaty matrix

C_n	C_1	C_2	C_3	C_4	C_5	Geomean	**Weights**
C_1	1	2	2	3	9	2.551	**0.390**
C_2	1/2	1	2	3	7	1.838	**0.281**
C_3	1/2	1/2	1	2	5	1.201	**0.184**
C_4	1/3	1/3	1/2	1	3	0.699	**0.107**
C_5	1/9	1/7	1/5	1/3	1	0.254	**0.039**

Source: Author example

There are multiple ways to calculate the weights in a Saaty matrix. For example, eigenvectors and eigenvalues can be used. However, a simpler yet highly suitable approach, as shown in the example in Table 9, is the geometric mean (geomean). According to Saaty and Vargas [12, p. 26], the geometric mean is the only aggregation procedure that satisfies the conditions of separability, unanimity, homogeneity, and reciprocity. As with other weighting methods, the geometric means are then normalized to values out of 1 by diving them by the total.

2.2 Alternative evaluation

Table 10: An example of Saaty method alternative evaluation

C_i	A_1	A_2	A_3	Geomean	**Weights**
A_1	1	1/3	1/7	0.362	**0.088**
A_2	3	1	1/3	1	**0.243**
A_3	7	3	1	2.759	**0.669**

Source: Author example

Alternative evaluation for the Saaty method is essentially the same procedure as that for Fuller triangle pairwise comparison, but with the aggregation approach selected for Saaty method criteria weighting. Table 10 and Table 11 respectively show the alternative evaluation and results for this example.

Table 11: Partial results based on the single evaluated criterion and equivalent full results

A_n	**Partial results (one criterion)**	**Equivalent full result values**
A_1	0.034	0.087
A_2	0.095	0.244
A_3	0.261	0.669

Source: Author example

2.3 Consistency verification

$$CR = \frac{CI}{RI}$$

Equation 1: Calculation of the consistency ratio

Source: [13, p. 447]

For the Saaty method, it is critical to verify that matrices are correctly assembled; that is, that the values they hold are internally consistent. This can be done by calculating a consistency ratio for each Saaty matrix used and ensuring that it is less than 0.1 in every case. A consistency ratio (CR) is equal to the calculated consistency index (CI) divided by the random consistency index (RI), as shown in Equation 1. [13, p. 447]

Table 12: An example of Saaty method alternative evaluation with an inconsistent matrix

C_i	A_1	A_2	A_3	Geomean	**Weights**
A_1	1	1/5	1/9	0.281	**0.058**
A_2	5	1	1/5	1	**0.207**
A_3	9	5	1	3.557	**0.735**

Source: Author example

The random consistency index is obtained from a given list of values that depend only upon the matrix size. Alonso and Lamata [13, p. 449] provide a table of RI(n) values for matrix sizes n from 3x3 up to a maximum of 15 (where available) from various authors. These are based on experimental simulations with run counts ranging from a low of 1000 to 100000 at most, the latter number being used for the authors' own values. Saaty's Wharton index, produced from 500 simulation runs for matrix sizes up to 11, may be considered the "reference list" and is used for consistency verification here.

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Equation 2: Calculation of the consistency index

Source: [13, p. 447]

As shown in Equation 2, the calculated consistency index is a function of the matrix size n, as with the RI, but also of the maximum eigenvalue of the matrix λ_{max}. Table 13 provides CI and CR values for the Saaty matrix example tables given here. The consistency ratios for Table 9 and Table 10 are well within the acceptable range, while that for the special example Table 12 is just outside it and the matrix is therefore considered inconsistent in that case.

Table 13: Consistency indices and ratios for Saaty matrix examples

Table	**n**	**RI (Wharton)**	**λ_{max}**	**CI**	**CR (< 0.1)**
Table 9	5	1.12	5.063	0.016	0.014
Table 10	3	0.58	3.007	0.004	0.006
Table 12	3	0.58	3.117	0.058	0.101

Source: Author example, calculated with Equation 1 and Equation 2

2.4 Software implementations

An important example of AHP and ANP software which bears specific mention is Super Decisions, “the only free educational software that implements AHP and ANP”. It was developed by the team of Thomas L. Saaty, and is sponsored by the Creative Decisions Foundation, a non-profit organization established by Dr. Saaty and his wife Rozann Whitaker Saaty. [14] Super Decisions can therefore be considered the “reference software” for the AHP and ANP methods.

Both for this reason and due to its being freely available for educational purposes, it has been selected for use here where specialized AHP/ANP software is called for, particularly for purposes of comparison with manual and/or semi-automated calculations. In the analysis tables, “SC” (“software comparison”, chosen instead of “SD” both to avoid confusion with the common usage for standard deviation and to use a generic term) indicates values obtained from Super Decisions, which in all cases should differ by no more than rounding error.

The AHP and ANP methods have seen numerous other software implementations, including many proprietary and commercial packages. There have also been innovative approaches to delivering the availability of this methodology, including online-only software. One particularly notable example is AHP-OS, as it is the subject of a published paper on the topic authored by its creator. [15]

3 PUBLIC ADMINISTRATION AND THE EUROPEAN UNION

One of the applications of multiple-criteria decision making is in the field of public administration. [16] Public administration is a broad field with a variety of definitions of its scope. It can be viewed as the implementation of legislation, or even the executive branch of government itself. [17] Ultimately, public administration is the operation of government at all its levels, in which public servants carry out functions for and deliver services to the population which the government serves. [18]

At the highest levels of government, public servants are tasked with implementing national and international laws and treaties. Perhaps nowhere else is this so fundamental as in the bureaucracy of the European Union (EU), which as the most prominent supranational body in the modern international system must often be able to present a common approach which considers the interests of dozens of member states in its decision-making. Public administrators in the EU follow a complex network of legislation to deliver upon policies with possibly hard-to-define but nevertheless high expectations from numerous parties involved.

3.1 The euro convergence criteria

Within the European Union membership, a common question is that of the ongoing adoption of the EU's common currency, the euro. While most member states of the EU have also joined the eurozone, the group of countries with the euro as their recognized official currency, a number have remained outside the bloc. The technical reason for this is that these countries have not fulfilled the euro convergence criteria, also known as the Maastricht criteria: a set of objective parameters that primarily measure the state of a country's finances, thus assessing readiness to adopt the euro as a currency. Given the nature of these criteria, they can themselves be considered public administration data.

The five measured convergence criteria are as follows:

- The rate of inflation
- The ratio of the budget deficit to GDP
- The ratio of the national debt to GDP
- The change in the exchange rate versus the euro
- The long-term interest rate

Certain additional considerations that form part of the overall convergence decision, such as whether a country is subject to an excessive deficit procedure or whether a currency participates in the European Exchange Rate Mechanism (ERM) II, are binary criteria and are therefore excluded from the analysis here.

For those EU members remaining outside the eurozone (and without opt-out arrangements, as in the case of Denmark), a semiregular Convergence Report detailing each candidate country's progress in terms of fulfilling the criteria in the three years prior to the report is published by both the European Central Bank (ECB) and the European Commission (EC). Over the years of the euro's existence, there has been a significant trend of the eurozone adding members. The list of countries included in the Convergence Reports has thus greatly changed over time in both number and composition, with states fulfilling the criteria and deciding to enter the eurozone just as the EU accepts new entrants itself.

3.2 Comparing countries as alternatives

The AHP/ANP methodology requires multiple alternatives to choose from, with each alternative being compared to the others based on each criterion. Therefore, the countries listed in a particular report are compared to each other based on their criteria data for a given year. The 2020 report includes data for Bulgaria (BG), Czechia (CZ), Croatia (HR), Hungary (HU), Poland (PL), Romania (RO), and Sweden (SE), and the latest, 2020 data for these countries serves as a starting point for analysis.

A major question arises in using the AHP/ANP system with arbitrary data: how to transform the input into not just a pairwise comparison, but specifically one utilizing the 1-to-9 Saaty scale. Doing so requires building an algorithm to transform the data based on its specific characteristics; a suggested approach follows.

4 ALGORITHM PROPOSAL

Table 14: Convergence Report data for 2020

Country	BG	CZ	HR	HU	PL	RO	SE	*Reference*
Inflation	2.6	2.9	0.9	3.7	2.8	3.7	1.6	*1.8*
Deficit	-2.8	-6.7	-7.1	-5.2	-9.5	-9.2	-5.6	*-3.0*
Debt	25.5	38.7	88.6	75.0	58.5	46.2	42.6	*60.0*
Exchange	0.0	0.2	-1.0	-4.3	-0.6	-1.1	-0.8	*N/A*
Interest	0.3	1.5	0.9	2.3	2.2	4.4	-0.1	*2.9*

Source: [19, p. 44]

For most of the criteria – inflation rates, debt ratios, and interest rates – assemble the data for a particular criterion in a particular year by country as presented in the relevant ECB Convergence Report. For deficit ratios, enter the values with reversed signs: deficits positive, and surpluses negative. In the case of exchange rates, enter only the positive magnitudes (absolute values) of the original data. Table 14 shows the full decision table for 2020, with all the input data for that year. The example calculations that follow use the interest rate criterion.

Table 15: 2020 interest rate data in differences with standard deviation (σ)

σ	1.982577172	0.3	1.5	0.9	2.3	2.2	4.4	-0.1
Interest	**Country**	BG	CZ	HR	HU	PL	RO	SE
0.3	Bulgaria	0	-1.2	-0.6	-2	-1.9	-4.1	0.4
1.5	Czechia	1.2	0	0.6	-0.8	-0.7	-2.9	1.6
0.9	Croatia	0.6	-0.6	0	-1.4	-1.3	-3.5	1
2.3	Hungary	2	0.8	1.4	0	0.1	-2.1	2.4
2.2	Poland	1.9	0.7	1.3	-0.1	0	-2.2	2.3
4.4	Romania	4.1	2.9	3.5	2.1	2.2	0	4.5
-0.1	Sweden	-0.4	-1.6	-1	-2.4	-2.3	-4.5	0

Source: Author calculation, based on data from Table 14

Arrange the countries and their respective data values in both rows and columns of a single table for pairwise comparison. In each cell, subtract the column value from the row value. Table 15 shows this step for this example, with original values also provided for reference.

Table 16: 2020 interest rate data normalized by dividing it by its standard deviation

Interest	BG	CZ	HR	HU	PL	RO	SE
Bulgaria	0.000	-0.605	-0.303	-1.009	-0.958	-2.068	0.202
Czechia	0.605	0.000	0.303	-0.404	-0.353	-1.463	0.807
Croatia	0.303	-0.303	0.000	-0.706	-0.656	-1.765	0.504
Hungary	1.009	0.404	0.706	0.000	0.050	-1.059	1.211
Poland	0.958	0.353	0.656	-0.050	0.000	-1.110	1.160
Romania	2.068	1.463	1.765	1.059	1.110	0.000	2.270
Sweden	-0.202	-0.807	-0.504	-1.211	-1.160	-2.270	0.000

Source: Author calculation, based on data from Table 14

Next, calculate the population standard deviation σ of the entire table (excluding the original values if they are provided), with precision for this calculation result as high as feasible. Then divide each value in the table by the calculated standard deviation. Table 16 shows the result of this procedure for this example.

Table 17: Intervals for converting standard deviation (σ) values to Saaty scale values

From σ	-2.5	-2	-1.5	-1	-0.5	0.5	1	1.5	2
To σ	-2	-1.5	-1	-0.5	0.5	1	1.5	2	2.5
Value	**9**	**7**	**5**	**3**	**1**	**1/3**	**1/5**	**1/7**	**1/9**

Source: Author

Finally, convert the calculated table values according to the intervals provided in Table 17. The result of the conversion process for this example is shown in Table 18.

Table 18: The result of the algorithm for the example data

Interest	BG	CZ	HR	HU	PL	RO	SE
Bulgaria	1	3	1	5	3	9	1
Czechia	1/3	1	1	1	1	5	1/3
Croatia	1	1	1	3	3	7	1/3
Hungary	1/5	1	1/3	1	1	5	1/5
Poland	1/3	1	1/3	1	1	5	1/5
Romania	1/9	1/5	1/7	1/5	1/5	1	1/9
Sweden	1	3	3	5	5	9	1

Source: Author calculation, based on data from Table 14

4.1 Methodological rationale

For inflation rates, government debt to GDP ratios, government deficit to GDP ratios, and interest rates, the ECB provides maximum reference values that should not be exceeded by a country, as shown in the last column in Table 14. As a pairwise comparison is performed, the reference values are not used directly. However, they serve as guidelines for what to consider a “better” or “worse” value.

These maxima are the only limits considered for all these criteria; notably, no minimum values are specified. This appears to be in accordance with the nature of these criteria, particularly in that none of them admit excessive negative values in practical scenarios. In the case of government debt, the lowest possible value is zero. A negative deficit, or surplus, can outright be considered desirable for the government in question. For interest rates, a limitation known as the “zero lower bound”, which despite the term is often slightly below zero, nevertheless highlights that significant negative values are not considered feasible. [20] Similarly, low deflation (negative inflation) is possible, but an equivalent of hyperinflation is essentially unknown, to the point that “hyperdeflation” is often not a recognized term.

Emphasizing the rarity of such an occurrence, the one possible example found in a search of the literature deals not with ordinary currencies like the euro, but with cryptocurrency. [21]

Therefore, the pairwise comparison proceeds with the assumption that – with one sign adjustment – for four out of the five criteria, the lower the value the better off a country is deemed to be in terms of the criterion. The sign of the deficit criterion is reversed compared to the approach used in the ECB reports: there, surplus is positive and deficit negative; but as it is the deficit that is the criterion here, as well as for consistency of methodology with that used for the other three criteria, deficit is defined as positive and surplus negative.

For the exchange rate, no reference value is provided. Furthermore, although the ECB does specify devaluation against the euro as an example of a particular threshold, change in exchange rates is more symmetric than that of the other criteria used, as both excessive and especially rapid appreciation and depreciation can be considered undesirable volatility. In the ERM system, currencies are kept within a specified band – currently 15%, but previously 2.25% in the ERM I system used until 1993 – in both directions. [22] Therefore, unlike with the other criteria, the *de facto* reference value is considered double-sided, and thus the change in exchange rates is first converted to absolute values before differences are taken.

The next step is to normalize the data, to implement a consistent conversion process regardless of the original values. A standard approach for doing so is by changing to standard scores, or z-scores. By using differences in the previous stage, the pairwise comparisons already have a mean of zero, as the table is symmetric from the start. Therefore, only the standard deviation of the entire table need be calculated, with the recording of additional significant digits preferred for accuracy in the following division step. The population standard deviation is used instead of the sample standard deviation, as every group of countries is considered a distinct "population", with data for each group in a separate report.

At this point, the values have been normalized, but still do not follow the Saaty scale. Converting them requires some method of assigning the z-scores to the Saaty values of 1, 3, 5, 7, 9, and the reciprocals of each. (As previously mentioned in the general discussion of the Saaty method, the in-between even numerals can also be used, but for simplicity they are not employed here.)

The intervals in the suggested assignment method shown in Table 17 are primarily derived from desiring a good fit to the data which uses the entire 1-9 range with sufficient distinctions and without excessive clustering, yet critically still fits all data points. However, they are also informed by the statistical principle that for most random variables, almost all data points fit within 3 standard deviations; this is most associated with normal distributions but applies to a broad range of variables, provided that their distributions satisfy certain conditions. [23] This data seems to demonstrate the principle quite strongly, as 2.5 standard deviations seem to be both necessary and sufficient in virtually all examined cases (rare exceptions are described in the historical comparison). It is important to note that between -0.5 and 0.5 standard deviations values are considered “identical” for purposes of this analysis, as those within this range are not necessarily distinct enough to be classified accurately.

4.2 Criteria comparison

The AHP/ANP methodology also requires a table comparing all the criteria to each other. For this specific case study, however, no data about their relative weights is available. In fact, satisfying all the convergence criteria is the overall requirement for each country. For purposes of the AHP system, this can be interpreted as necessitating equal weights for all the criteria, as if they are all required then they are all “fully important”. Therefore, the criteria comparison is prepared as shown in Table 19, with all entered values being 1. Mathematically, this serves to “pass through” the values from the individual criteria tables.

Table 19: The criteria matrix with only default (1) values

Criterion	Inflation	Deficit	Debt	Exchange	Interest	Geomean	**Weights**
Inflation	1	1	1	1	1	1	**0.2**
Deficit	1	1	1	1	1	1	**0.2**
Debt	1	1	1	1	1	1	**0.2**
Exchange	1	1	1	1	1	1	**0.2**
Interest	1	1	1	1	1	1	**0.2**

Source: Author

Such an approach could of course be considered a limitation, as normally a major part of the AHP process is deciding upon the relative weights of the criteria to each other. However, this approach avoids introducing unwarranted bias to the system, and as shall be seen nevertheless yields very useful results. In practice, a decision maker could make more nuanced use of the algorithm simply by adjusting the values in this table, which adds a great deal of flexibility.

4.3 Synthesizing preferences

The remaining steps to complete the procedure follow the standard AHP process. First, the weights need to be calculated for each criterion using the geometric mean as discussed before.

Table 20: Weights for the inflation rate criterion (2020 data)

Inflation	BG	CZ	HR	HU	PL	RO	SE	Geomean	**Weights**
Bulgaria	1	1	1/5	3	1	3	1/3	0.930	**0.091**
Czechia	1	1	1/5	3	1	3	1/3	0.930	**0.091**
Croatia	5	5	1	9	5	9	3	4.369	**0.427**
Hungary	1/3	1/3	1/9	1	1/3	1	1/7	0.346	**0.034**
Poland	1	1	1/5	3	1	3	1/3	0.930	**0.091**
Romania	1/3	1/3	1/9	1	1/3	1	1/7	0.346	**0.034**
Sweden	3	3	1/3	7	3	7	1	2.387	**0.233**

Source: Author calculation using the proposed algorithm, based on data from Table 14

Table 21: Weights for the deficit ratio criterion (2020 data)

Deficit	BG	CZ	HR	HU	PL	RO	SE	Geomean	**Weights**
Bulgaria	1	5	5	3	9	9	3	4.061	**0.419**
Czechia	1/5	1	1	1	3	3	1	1.088	**0.112**
Croatia	1/5	1	1	1/3	3	3	1	0.930	**0.096**
Hungary	1/3	1	3	1	5	5	1	1.584	**0.163**
Poland	1/9	1/3	1/3	1/5	1	1	1/5	0.337	**0.035**
Romania	1/9	1/3	1/3	1/5	1	1	1/5	0.337	**0.035**
Sweden	1/3	1	1	1	5	5	1	1.354	**0.140**

Source: Author calculation using the proposed algorithm, based on data from Table 14

Table 22: Weights for the debt ratio criterion (2020 data)

Debt	BG	CZ	HR	HU	PL	RO	SE	Geomean	**Weights**
Bulgaria	1	1	9	7	5	3	3	3.113	**0.327**
Czechia	1	1	7	5	3	1	1	1.944	**0.204**
Croatia	1/9	1/7	1	1	1/5	1/5	1/7	0.265	**0.028**
Hungary	1/7	1/5	1	1	1/3	1/5	1/5	0.325	**0.034**
Poland	1/5	1/3	5	3	1	1	1/3	0.855	**0.090**
Romania	1/3	1	5	5	1	1	1	1.354	**0.142**
Sweden	1/3	1	7	5	3	1	1	1.662	**0.175**

Source: Author calculation using the proposed algorithm, based on data from Table 14

Table 23: Weights for the exchange rate criterion (2020 data)

Exchange	BG	CZ	HR	HU	PL	RO	SE	Geomean	**Weights**
Bulgaria	1	1	3	9	1	3	1	1.873	**0.225**
Czechia	1	1	1	9	1	1	1	1.369	**0.165**
Croatia	1/3	1	1	7	1	1	1	1.129	**0.136**
Hungary	1/9	1/9	1/7	1	1/7	1/7	1/7	0.176	**0.021**
Poland	1	1	1	7	1	1	1	1.320	**0.159**
Romania	1/3	1	1	7	1	1	1	1.129	**0.136**
Sweden	1	1	1	7	1	1	1	1.320	**0.159**

Source: Author calculation using the proposed algorithm, based on data from Table 14

Table 24: Weights for the interest rate criterion (2020 data)

Interest	BG	CZ	HR	HU	PL	RO	SE	Geomean	**Weights**
Bulgaria	1	3	1	5	3	9	1	2.358	**0.251**
Czechia	1/3	1	1	1	1	5	1/3	0.919	**0.098**
Croatia	1	1	1	3	3	7	1/3	1.545	**0.164**
Hungary	1/5	1	1/3	1	1	5	1/5	0.679	**0.072**
Poland	1/3	1	1/3	1	1	5	1/5	0.731	**0.078**
Romania	1/9	1/5	1/7	1/5	1/5	1	1/9	0.203	**0.022**
Sweden	1	3	3	5	5	9	1	2.967	**0.316**

Source: Author calculation using the proposed algorithm, based on data from Table 14

The next step is to verify all consistency indices and ratios for the matrices used in the overall calculation, including all five individual criterion tables as well as that comparing the criteria (Table 19). Table 25 provides the calculated CI and CR values for all the matrices used here.

Table 25: Consistency indices and ratios for all 2020 data matrices

Table	**n**	**RI (Wharton)**	**λ_{max}**	**CI**	**CR (< 0.1)**	***SC (< 0.1)***
Table 19	5	1.12	5	0	0	*0*
Table 20	7	1.32	7.092	0.015	0.012	*0.011*
Table 21	7	1.32	7.164	0.027	0.021	*0.020*
Table 22	7	1.32	7.260	0.043	0.033	*0.032*
Table 23	7	1.32	7.192	0.032	0.024	*0.024*
Table 24	7	1.32	7.271	0.045	0.034	*0.033*

Source: Author calculation, using Equation 1 and Equation 2

Finally, the values are synthesized from all tables used, and an overall ranking calculated. Table 26 shows these results, with the countries reordered according to their obtained ranking. Figure 5 provides a graphical overview of the results, visualizing the distances between ranks.

Table 26: Total preferences for all 2020 data alternatives, ordered by ranking

Ranking	**Country**	**Total**	***SC***
1	Bulgaria	0.263	*0.265*
2	Sweden	0.204	*0.203*
3	Croatia	0.170	*0.172*
4	Czechia	0.134	*0.133*
5	Poland	0.090	*0.089*
6	Romania	0.074	*0.073*
7	Hungary	0.065	*0.065*

Source: Author calculation

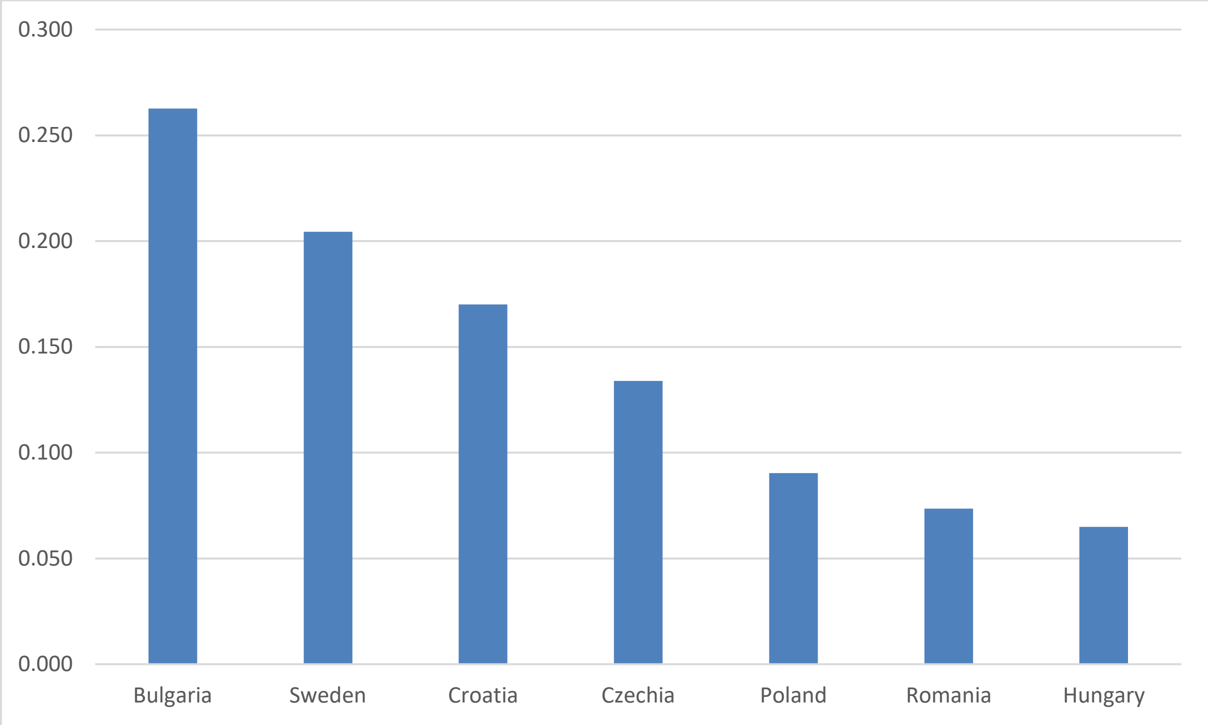

Figure 5: Graph of total preferences for all 2020 data alternatives, ordered by ranking

Source: Author

5 HISTORICAL COMPARISON

It is instructive to not only test the algorithm with the most recently available data, but also see how it performs with historical data, and whether any further insights can be drawn from this analysis. The 2010 and 2004 Convergence Reports are chosen for historical comparison. Importantly, both reports cover even larger numbers of countries than the 2020 edition. The 2004 report also represents a large wave of EU expansion that sees many countries included for the first time, while using the 2010 edition allows for a convenient timespan between datasets of exactly a decade.

Two special cases must be handled during the analysis. As both happen to occur with the data for both reports, they are denoted by the same asterisk indicators, * and ** respectively, and discussed here together before proceeding.

A single asterisk (*) is used in Table 30 for the Estonia-Hungary and reciprocal Hungary-Estonia comparisons, and in Table 37 for Lithuania-Slovakia and Slovakia-Lithuania. This indicator is placed due to those being the only values that exceeded the 2.5 standard deviations provided for in Table 17. The conversion interval was extended to 3 standard deviations for those cells, using the same values as for the 2.5 case.

A double asterisk (**) is used for the rows and columns for Estonia in both Table 32 and Table 40. This is because, as seen in Table 27 and Table 35, no interest rate data is available for Estonia in either report. For purposes of the calculations performed, the respective values 15 and 10 were substituted. While somewhat arbitrary, they are larger than the values for all other countries, which ensures that the missing value does not afford an unwarranted advantage in the comparisons in either case.

For the 2010 data, when compared to a zero value (which would be lower than that for all other countries), the replacement has no effect on the final rankings. (In fact, despite suffering a significant penalty because of this substitution in the synthesized total preferences, Estonia remains ranked in first place.) For the 2004 report, entering a zero value causes some calculations to go beyond not just 2.5 – as in the first of the special cases discussed here – but also 3 standard deviations, indicating the unsuitability of such an alternative replacement.

5.1 Full comparison (2010 data)

In the 2010 Convergence Report, almost all the same countries are included except for Croatia, at the time not yet an EU member. In its place however are three other countries, all of which have since joined the eurozone and are thus no longer included in Convergence

Reports: Estonia (EE), Latvia (LV), and Lithuania (LT). Table 27 shows the full decision table for data from this report for 2010.

Table 27: Convergence Report data for 2010

Country	BG	CZ	EE	LV	LT	HU	PL	RO	SE	*Reference*
Inflation	1.7	0.3	-0.7	0.1	2.0	4.8	3.9	5.0	2.1	*1.0*
Deficit	-2.8	-5.7	-2.4	-8.6	-8.4	-4.1	-7.3	-8.0	-2.1	*-3.0*
Debt	17.4	39.8	9.6	48.5	38.6	78.9	53.9	30.5	42.6	*60.0*
Exchange	0.0	2.6	0.0	-0.4	0.0	4.5	8.4	2.9	6.8	*N/A*
Interest	6.9	4.7	N/A	12.7	12.1	8.4	6.1	9.4	3.3	*6.0*

Source: [24, p. 33]

Once again, individual criterion tables – Table 28, Table 29, Table 30, Table 31, and Table 32 – are constructed using the geometric mean.

Table 28: Weights for the inflation rate criterion (2010 data)

Inflation	BG	CZ	EE	LV	LT	HU	PL	RO	SE	Geomean	**Weights**
Bulgaria	1	1/3	1/3	1/3	1	5	3	5	1	1.120	**0.089**
Czechia	3	1	1	1	3	7	5	7	3	2.658	**0.211**
Estonia	3	1	1	1	3	7	7	9	5	3.003	**0.239**
Latvia	3	1	1	1	3	7	5	7	3	2.658	**0.211**
Lithuania	1	1/3	1/3	1/3	1	5	3	5	1	1.120	**0.089**
Hungary	1/5	1/7	1/7	1/7	1/5	1	1	1	1/3	0.324	**0.026**
Poland	1/3	1/5	1/7	1/5	1/3	1	1	1	1/3	0.391	**0.031**
Romania	1/5	1/7	1/9	1/7	1/5	1	1	1	1/5	0.297	**0.024**
Sweden	1	1/3	1/5	1/3	1	3	3	5	1	1.000	**0.080**

Source: Author calculation using the proposed algorithm, based on data from Table 27

Table 29: Weights for the deficit ratio criterion (2010 data)

Deficit	BG	CZ	EE	LV	LT	HU	PL	RO	SE	Geomean	**Weights**
Bulgaria	1	3	1	7	7	1	5	5	1	2.490	**0.199**
Czechia	1/3	1	1/3	3	3	1	1	3	1/5	0.945	**0.076**
Estonia	1	3	1	7	7	1	5	7	1	2.584	**0.207**
Latvia	1/7	1/3	1/7	1	1	1/5	1	1	1/7	0.387	**0.031**
Lithuania	1/7	1/3	1/7	1	1	1/5	1	1	1/7	0.387	**0.031**
Hungary	1	1	1	5	5	1	3	5	1/3	1.710	**0.137**
Poland	1/5	1	1/5	1	1	1/3	1	1	1/5	0.518	**0.041**
Romania	1/5	1/3	1/7	1	1	1/5	1	1	1/7	0.402	**0.032**
Sweden	1	5	1	7	7	3	5	7	1	3.091	**0.247**

Source: Author calculation using the proposed algorithm, based on data from Table 27

Table 30: Weights for the debt ratio criterion (2010 data)

Debt	BG	CZ	EE	LV	LT	HU	PL	RO	SE	Geomean	**Weights**
Bulgaria	1	3	1	5	3	9	5	1	3	2.633	**0.218**
Czechia	1/3	1	1/5	1	1	5	3	1	1	1.000	**0.083**
Estonia	1	5	1	5	5	9*	7	3	5	3.661	**0.303**
Latvia	1/5	1	1/5	1	1	5	1	1/3	1	0.740	**0.061**
Lithuania	1/3	1	1/5	1	1	5	3	1	1	1.000	**0.083**
Hungary	1/9	1/5	1/9*	1/5	1/5	1	1/3	1/7	1/5	0.214	**0.018**
Poland	1/5	1/3	1/7	1	1/3	3	1	1/3	1	0.528	**0.044**
Romania	1	1	1/3	3	1	7	3	1	1	1.403	**0.116**
Sweden	1/3	1	1/5	1	1	5	1	1	1	0.885	**0.073**

Source: Author calculation using the proposed algorithm, based on data from Table 27

Table 31: Weights for the exchange rate criterion (2010 data)

Exchange	BG	CZ	EE	LV	LT	HU	PL	RO	SE	Geomean	**Weights**
Bulgaria	1	3	1	1	1	5	7	3	7	2.352	**0.194**
Czechia	1/3	1	1/3	1/3	1/3	1	5	1	3	0.829	**0.068**
Estonia	1	3	1	1	1	5	7	3	7	2.352	**0.194**
Latvia	1	3	1	1	1	3	7	3	7	2.222	**0.183**
Lithuania	1	3	1	1	1	5	7	3	7	2.352	**0.194**
Hungary	1/5	1	1/5	1/3	1/5	1	3	1	3	0.661	**0.054**
Poland	1/7	1/5	1/7	1/7	1/7	1/3	1	1/5	1	0.261	**0.021**
Romania	1/3	1	1/3	1/3	1/3	1	5	1	3	0.829	**0.068**
Sweden	1/7	1/3	1/7	1/7	1/7	1/3	1	1/3	1	0.292	**0.024**

Source: Author calculation using the proposed algorithm, based on data from Table 27

Table 32: Weights for the interest rate criterion (2010 data)

Interest	BG	CZ	EE**	LV	LT	HU	PL	RO	SE	Geomean	**Weights**
Bulgaria	1	1	7	5	3	1	1	1	1/3	1.484	**0.121**
Czechia	1	1	7	7	5	3	1	3	1	2.352	**0.192**
Estonia**	1/7	1/7	1	1	1/3	1/5	1/7	1/5	1/9	0.253	**0.021**
Latvia	1/5	1/7	1	1	1	1/3	1/5	1/3	1/7	0.356	**0.029**
Lithuania	1/3	1/5	3	1	1	1/3	1/5	1/3	1/7	0.441	**0.036**
Hungary	1	1/3	5	3	3	1	1	1	1/3	1.196	**0.098**
Poland	1	1	7	5	5	1	1	3	1/3	1.775	**0.145**
Romania	1	1/3	5	3	3	1	1/3	1	1/5	1.000	**0.082**
Sweden	3	1	9	7	7	3	3	5	1	3.393	**0.277**

Source: Author calculation using the proposed algorithm, based on data from Table 27

As before, all consistency indices and ratios are checked. Table 33 shows the result of this verification step, with Table 19 included again as it is reused for the analysis here.

Table 33: Consistency indices and ratios for all 2010 data matrices

Table	n	RI (Wharton)	λ_{max}	CI	CR (< 0.1)	*SC (< 0.1)*
Table 19	5	1.12	5	0	0	*0*
Table 28	9	1.45	9.201	0.025	0.017	*0.017*
Table 29	9	1.45	9.247	0.031	0.021	*0.021*
Table 30	9	1.45	9.380	0.047	0.033	*0.033*
Table 31	9	1.45	9.152	0.019	0.013	*0.013*
Table 32	9	1.45	9.326	0.041	0.028	*0.028*

Source: Author calculation, using Equation 1 and Equation 2

Finally, the overall preferences are synthesized and ordered by rank, as seen in Table 34 and Figure 6.

Table 34: Total preferences for all 2010 data alternatives, ordered by ranking

Ranking	Country	Total	*SC*
1	Estonia	0.193	*0.192*
2	Bulgaria	0.164	*0.163*
3	Sweden	0.140	*0.141*
4	Czechia	0.126	*0.126*
5	Latvia	0.103	*0.102*
6	Lithuania	0.087	*0.086*
7	Hungary	0.066	*0.067*
8	Romania	0.064	*0.065*
9	Poland	0.057	*0.057*

Source: Author calculation

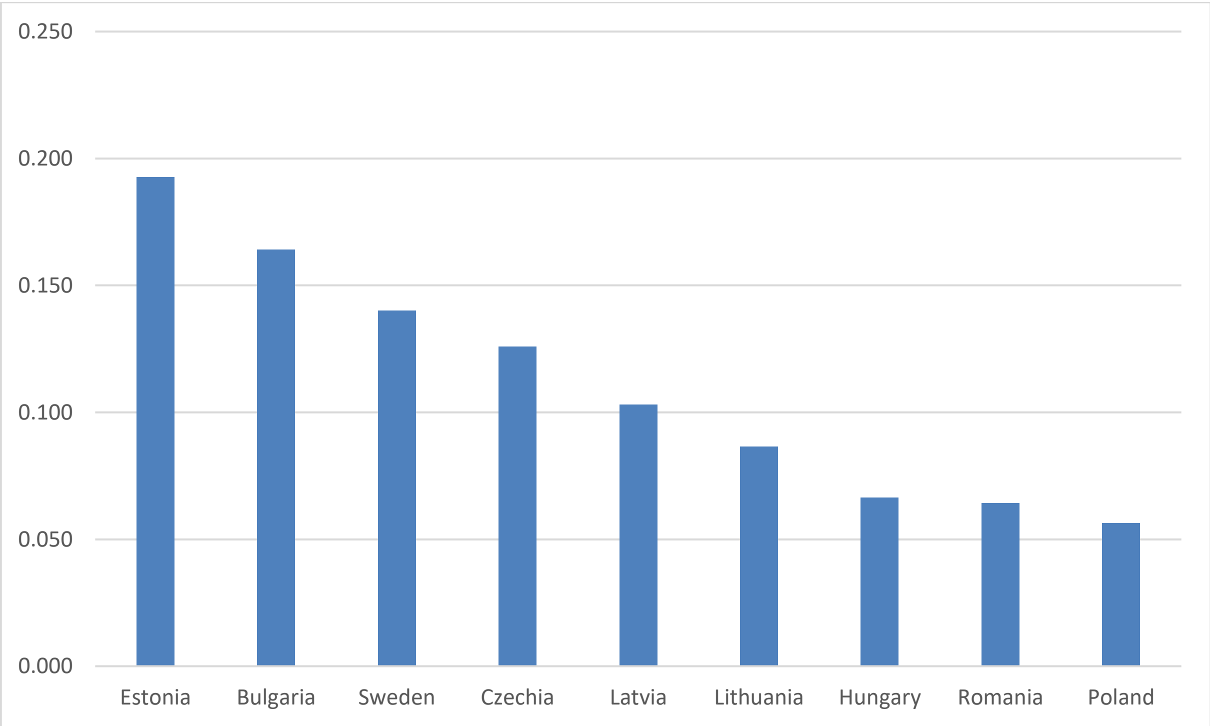

Figure 6: Graph of total preferences for all 2010 data alternatives, ordered by ranking

Source: Author

5.2 Partial comparison (2004 data)

The analysis for the 2004 report data, shown in Table 35, largely follows the same process again: Table 37, Table 38, Table 39, and Table 40 are for the individual criteria, Table 41 consistency verification, and Table 42 and Figure 7 ordered overall synthesized preferences.

However, there is a critical difference: exchange rate values are not provided along with the other data. Therefore, the analysis proceeds with only four criteria instead of five, necessitating a revised criteria comparison matrix with adjusted weights as seen in Table 36.

In addition, compared to the other Convergence Reports examined, the list of countries included is significantly different. This report covers the following countries: Czechia (CZ), Estonia (EE), Cyprus (CY), Latvia (LV), Lithuania (LT), Hungary (HU), Malta (MT), Poland (PL), Slovenia (SI), Slovakia (SE), and Sweden (SE). Except for Sweden, all these countries entered the EU in 2004 and are therefore included for the first time.

Table 35: Convergence Report data for 2004

Country	CZ	EE	CY	LV	LT	HU	MT	PL	SI	SK	SE	*Reference*
Inflation	1.8	2.0	2.1	4.9	-0.2	6.5	2.6	2.5	4.1	8.4	1.3	*2.4*
Deficit	-5.0	0.3	-5.2	-2.0	-2.6	-5.5	-5.2	-5.6	-2.3	-3.9	0.6	*-3*
Debt	37.9	4.8	72.6	14.7	21.4	59.9	73.8	47.2	30.8	44.5	51.6	*60*
Interest	4.7	N/A	5.2	5.0	4.7	8.1	4.7	6.9	5.2	5.1	4.7	*6.4*

Source: [25, p. 22]

Table 36: The criteria matrix with only default (1) values and without exchange rates

Criterion	Inflation	Deficit	Debt	Exchange	Interest	Geomean	**Weights**
Inflation	1	1	1	1	1	1	**0.25**
Deficit	1	1	1	1	1	1	**0.25**
Debt	1	1	1	1	1	1	**0.25**
Interest	1	1	1	1	1	1	**0.25**

Source: Author

Table 37: Weights for the inflation rate criterion (2004 data)

Inflation	CZ	EE	CY	LV	LT	HU	MT	PL	SI	SK	SE	Geomean	**Weights**
Czechia	1	1	1	3	1/3	5	1	1	3	7	1	1.527	**0.107**
Estonia	1	1	1	3	1/3	5	1	1	3	7	1	1.527	**0.107**
Cyprus	1	1	1	3	1/3	5	1	1	3	7	1	1.527	**0.107**
Latvia	1/3	1/3	1/3	1	1/7	1	1/3	1/3	1	5	1/5	0.509	**0.036**
Lithuania	3	3	3	7	1	7	3	3	5	9*	1	3.318	**0.232**
Hungary	1/5	1/5	1/5	1	1/7	1	1/5	1/5	1/3	3	1/7	0.338	**0.024**
Malta	1	1	1	3	1/3	5	1	1	1	7	1	1.382	**0.097**
Poland	1	1	1	3	1/3	5	1	1	1	7	1	1.382	**0.097**
Slovenia	1/3	1/3	1/3	1	1/5	3	1	1	1	5	1/3	0.741	**0.052**
Slovakia	1/7	1/7	1/7	1/5	1/9*	1/3	1/7	1/7	1/5	1	1/9	0.187	**0.013**
Sweden	1	1	1	5	1	7	1	1	3	9	1	1.864	**0.130**

Source: Author calculation using the proposed algorithm, based on data from Table 35

Table 38: Weights for the deficit ratio criterion (2004 data)

Deficit	CZ	EE	CY	LV	LT	HU	MT	PL	SI	SK	SE	Geomean	**Weights**
Czechia	1	1/7	1	1/3	1/3	1	1	1	1/3	1	1/7	0.520	**0.033**
Estonia	7	1	7	3	3	7	7	7	3	5	1	3.783	**0.241**
Cyprus	1	1/7	1	1/5	1/3	1	1	1	1/3	1	1/7	0.497	**0.032**
Latvia	3	1/3	5	1	1	5	5	5	1	3	1/3	1.795	**0.115**
Lithuania	3	1/3	3	1	1	3	3	3	1	1	1/5	1.288	**0.082**
Hungary	1	1/7	1	1/5	1/3	1	1	1	1/5	1/3	1/7	0.429	**0.027**
Malta	1	1/7	1	1/5	1/3	1	1	1	1/3	1	1/7	0.497	**0.032**
Poland	1	1/7	1	1/5	1/3	1	1	1	1/5	1/3	1/9	0.419	**0.027**
Slovenia	3	1/3	3	1	1	5	3	5	1	3	1/3	1.636	**0.104**
Slovakia	1	1/5	1	1/3	1	3	1	3	1/3	1	1/5	0.746	**0.048**
Sweden	7	1	7	3	5	7	7	9	3	5	1	4.054	**0.259**

Source: Author calculation using the proposed algorithm, based on data from Table 35

Table 39: Weights for the debt ratio criterion (2004 data)

Debt	CZ	EE	CY	LV	LT	HU	MT	PL	SI	SK	SE	Geomean	**Weights**
Czechia	1	1/5	5	1/3	1/3	3	5	1	1	1	1	1.048	**0.069**
Estonia	5	1	9	1	3	7	9	5	3	5	7	4.023	**0.263**
Cyprus	1/5	1/9	1	1/7	1/7	1	1	1/3	1/5	1/3	1/3	0.318	**0.021**
Latvia	3	1	7	1	1	5	7	5	3	3	5	2.981	**0.195**
Lithuania	3	1/3	7	1	1	5	7	3	1	3	3	2.225	**0.146**
Hungary	1/3	1/7	1	1/5	1/5	1	1	1	1/3	1/3	1	0.463	**0.030**
Malta	1/5	1/9	1	1/7	1/7	1	1	1/3	1/5	1/3	1/3	0.318	**0.021**
Poland	1	1/5	3	1/5	1/3	1	3	1	1/3	1	1	0.746	**0.049**
Slovenia	1	1/3	5	1/3	1	3	5	3	1	1	3	1.481	**0.097**
Slovakia	1	1/5	3	1/3	1/3	3	3	1	1	1	1	0.955	**0.062**
Sweden	1	1/7	3	1/5	1/3	1	3	1	1/3	1	1	0.724	**0.047**

Source: Author calculation using the proposed algorithm, based on data from Table 35

Table 40: Weights for the interest rate criterion (2004 data)

Interest	CZ	EE**	CY	LV	LT	HU	MT	PL	SI	SK	SE	Geomean	**Weights**
Czechia	1	9	1	1	1	5	1	3	1	1	1	1.562	**0.115**
Estonia**	1/9	1	1/9	1/9	1/9	1/3	1/9	1/5	1/9	1/9	1/9	0.158	**0.012**
Cyprus	1	9	1	1	1	5	1	3	1	1	1	1.562	**0.115**
Latvia	1	9	1	1	1	5	1	3	1	1	1	1.562	**0.115**
Lithuania	1	9	1	1	1	5	1	3	1	1	1	1.562	**0.115**
Hungary	1/5	3	1/5	1/5	1/5	1	1/5	1/3	1/5	1/5	1/5	0.310	**0.023**
Malta	1	9	1	1	1	5	1	3	1	1	1	1.562	**0.115**
Poland	1/3	5	1/3	1/3	1/3	3	1/3	1	1/3	1/3	1/3	0.575	**0.042**
Slovenia	1	9	1	1	1	5	1	3	1	1	1	1.562	**0.115**
Slovakia	1	9	1	1	1	5	1	3	1	1	1	1.562	**0.115**
Sweden	1	9	1	1	1	5	1	3	1	1	1	1.562	**0.115**

Source: Author calculation using the proposed algorithm, based on data from Table 35

Table 41: Consistency indices and ratios for all 2004 data matrices

Table	**n**	**RI (Wharton)**	λ_{max}	**CI**	**CR (< 0.1)**	***SC (< 0.1)***
Table 36	4	0.9	4	0	0	*0*
Table 37	11	1.51	11.410	0.041	0.027	*0.027*
Table 38	11	1.51	11.296	0.030	0.020	*0.020*
Table 39	11	1.51	11.397	0.040	0.026	*0.026*
Table 40	11	1.51	11.062	0.006	0.004	*0.004*

Source: Author calculation, using Equation 1 and Equation 2

Table 42: Total preferences for all 2004 data alternatives, ordered by ranking

Ranking	**Country**	**Total**	***SC***
1	Estonia	0.156	*0.155*
2	Lithuania	0.144	*0.145*
3	Sweden	0.138	*0.138*
4	Latvia	0.115	*0.115*
5	Slovenia	0.092	*0.093*
6	Czechia	0.081	*0.080*
7	Cyprus	0.069	*0.068*
8	Malta	0.066	*0.066*
9	Slovakia	0.060	*0.060*
10	Poland	0.054	*0.054*
11	Hungary	0.026	*0.026*

Source: Author calculation

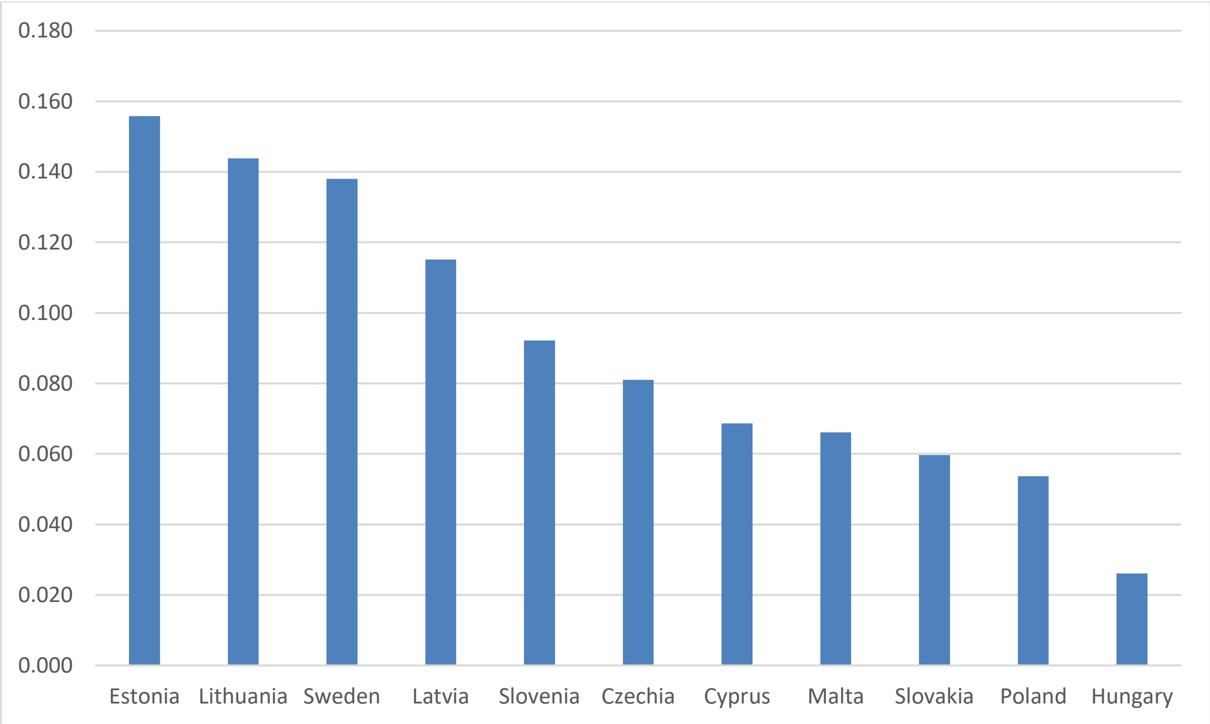

Figure 7: Graph of total preferences for all 2004 data alternatives, ordered by ranking

Source: Author

6 DISCUSSION OF PRACTICAL APPLICATION

It is doubtlessly desirable that such an algorithm serve as more than a mere theoretical curiosity. To examine the practical usefulness of the procedure, the output can be compared to real-world data. Specifically, one may compare when certain countries did in fact join either the eurozone itself, or the previously mentioned ERM II system in the most recent cases – for which it is not yet known when the countries in question may become full eurozone members. Of course, it is critical to note that such real-world data is fraught with political considerations. It is often a country’s internal political situation that determines such a complex question as that of switching its currency.

Nevertheless, the results of the algorithm reveal some striking parallels to actual join dates. The 2020 analysis places Bulgaria and Croatia as first and third respectively, and out of the seven candidate countries those are the two that entered the ERM II system in that year. Notably, Romania – which was the only country to join the EU at the same time as Bulgaria in 2007, and the only other country to become an EU member since then at all except for Croatia (joined 2013) – is placed second-last on the list, when given these facts such a system, dealing only with national financial data, could have been expected to group it with those two.

But it is probably the 2010 comparison that yields the most notable output. As already mentioned, Estonia, Latvia, and Lithuania all joined the eurozone in the years following that report: Estonia in 2011, Latvia in 2014, and Lithuania in 2015. The results of the system place these countries first, fifth, and sixth, respectively. Considering that the algorithm does not incorporate information about the political considerations that may have caused the other six countries to remain outside the eurozone a decade later, it is intriguing that it orders the three countries that did join correctly. The ranking even seems to correspond closely to the specific timelines for each country’s entry – Estonia entered the very next year after the report’s publication, and is ranked first, whereas the other two countries took several years to do so. The strength of Estonia’s placement especially is bolstered by the ranking disadvantage it was at due to a missing interest rate value, as discussed at length in the historical comparison – despite being deliberately “weighed down” to some extent, the system nevertheless produced the same historically-accurate rankings (and not just for Estonia, but for all three countries).

However, the algorithm performed very poorly in the 2004 historical comparison, with the rankings having virtually no correlation to actual join dates. Whether this has an external cause such as the missing criterion or increased volatility of national financial data during a large wave of EU expansion, or is simply a consequence of the algorithm itself, is unclear.

CONCLUSION

Out of numerous multiple-criteria decision-making systems, several have been described in detail and many more examined. The Analytic Hierarchy Process, one of the most common tools for this purpose, was chosen as the main system to use for analysis of a case study from the field of public administration.

The selected case study focuses on the euro convergence criteria, the set of national financial variables evaluated by European Union institutions on a semiregular basis to assess readiness of member countries to join the eurozone. The five specific criteria used in the analysis are the core indicators of inflation rates, deficit ratios, debt ratios, exchange rates, and interest rates.

Following a suggested algorithm for converting the data for these criteria to the standard scale used for the Analytic Hierarchy Process, candidate countries are compared and ranked from three reporting years: 2020 (the latest data), 2010, and 2004. In the first two of these cases, but not the third, the results appear to exhibit striking similarities to when countries did in fact join either the eurozone or the closely linked European Exchange Rate Mechanism, highlighting albeit with some caveats the potential predictive power of the applied algorithm.

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LIST OF APPENDICES

Appendix A – Criteria tables for 2020 data

(The corresponding values for interest rates are already provided in Table 15 and Table 16.)

Table 43: 2020 inflation rate data in differences with standard deviation (σ)

σ	1.356465997	2.6	2.9	0.9	3.7	2.8	3.7	1.6
Inflation	**Country**	BG	CZ	HR	HU	PL	RO	SE
2.6	Bulgaria	0	-0.3	1.7	-1.1	-0.2	-1.1	1
2.9	Czechia	0.3	0	2	-0.8	0.1	-0.8	1.3
0.9	Croatia	-1.7	-2	0	-2.8	-1.9	-2.8	-0.7
3.7	Hungary	1.1	0.8	2.8	0	0.9	0	2.1
2.8	Poland	0.2	-0.1	1.9	-0.9	0	-0.9	1.2
3.7	Romania	1.1	0.8	2.8	0	0.9	0	2.1
1.6	Sweden	-1	-1.3	0.7	-2.1	-1.2	-2.1	0

Source: Author calculation, based on data from Table 14

Table 44: 2020 inflation rate data normalized by dividing it by its standard deviation

Inflation	BG	CZ	HR	HU	PL	RO	SE
Bulgaria	0.000	-0.221	1.253	-0.811	-0.147	-0.811	0.737
Czechia	0.221	0.000	1.474	-0.590	0.074	-0.590	0.958
Croatia	-1.253	-1.474	0.000	-2.064	-1.401	-2.064	-0.516
Hungary	0.811	0.590	2.064	0.000	0.663	0.000	1.548
Poland	0.147	-0.074	1.401	-0.663	0.000	-0.663	0.885
Romania	0.811	0.590	2.064	0.000	0.663	0.000	1.548
Sweden	-0.737	-0.958	0.516	-1.548	-0.885	-1.548	0.000

Source: Author calculation, based on data from Table 14

Table 45: 2020 deficit ratio data in differences with standard deviation (σ)

σ	3.06261193	2.8	6.7	7.1	5.2	9.5	9.2	5.6
Deficit	**Country**	BG	CZ	HR	HU	PL	RO	SE
2.8	Bulgaria	0	-3.9	-4.3	-2.4	-6.7	-6.4	-2.8
6.7	Czechia	3.9	0	-0.4	1.5	-2.8	-2.5	1.1
7.1	Croatia	4.3	0.4	0	1.9	-2.4	-2.1	1.5
5.2	Hungary	2.4	-1.5	-1.9	0	-4.3	-4	-0.4
9.5	Poland	6.7	2.8	2.4	4.3	0	0.3	3.9
9.2	Romania	6.4	2.5	2.1	4	-0.3	0	3.6
5.6	Sweden	2.8	-1.1	-1.5	0.4	-3.9	-3.6	0

Source: Author calculation, based on data from Table 14

Table 46: 2020 deficit ratio data normalized by dividing it by its standard deviation

Deficit	BG	CZ	HR	HU	PL	RO	SE
Bulgaria	0.000	-1.273	-1.404	-0.784	-2.188	-2.090	-0.914
Czechia	1.273	0.000	-0.131	0.490	-0.914	-0.816	0.359
Croatia	1.404	0.131	0.000	0.620	-0.784	-0.686	0.490
Hungary	0.784	-0.490	-0.620	0.000	-1.404	-1.306	-0.131
Poland	2.188	0.914	0.784	1.404	0.000	0.098	1.273
Romania	2.090	0.816	0.686	1.306	-0.098	0.000	1.175
Sweden	0.914	-0.359	-0.490	0.131	-1.273	-1.175	0.000

Source: Author calculation, based on data from Table 14

Table 47: 2020 debt ratio data in differences with standard deviation (σ)

σ	28.75685544	25.5	38.7	88.6	75	58.5	46.2	42.6
Debt	**Country**	BG	CZ	HR	HU	PL	RO	SE
25.5	Bulgaria	0	-13.2	-63.1	-49.5	-33	-20.7	-17.1
38.7	Czechia	13.2	0	-49.9	-36.3	-19.8	-7.5	-3.9
88.6	Croatia	63.1	49.9	0	13.6	30.1	42.4	46
75	Hungary	49.5	36.3	-13.6	0	16.5	28.8	32.4
58.5	Poland	33	19.8	-30.1	-16.5	0	12.3	15.9
46.2	Romania	20.7	7.5	-42.4	-28.8	-12.3	0	3.6
42.6	Sweden	17.1	3.9	-46	-32.4	-15.9	-3.6	0

Source: Author calculation, based on data from Table 14

Table 48: 2020 debt ratio data normalized by dividing it by its standard deviation

Debt	BG	CZ	HR	HU	PL	RO	SE
Bulgaria	0.000	-0.459	-2.194	-1.721	-1.148	-0.720	-0.595
Czechia	0.459	0.000	-1.735	-1.262	-0.689	-0.261	-0.136
Croatia	2.194	1.735	0.000	0.473	1.047	1.474	1.600
Hungary	1.721	1.262	-0.473	0.000	0.574	1.002	1.127
Poland	1.148	0.689	-1.047	-0.574	0.000	0.428	0.553
Romania	0.720	0.261	-1.474	-1.002	-0.428	0.000	0.125
Sweden	0.595	0.136	-1.600	-1.127	-0.553	-0.125	0.000

Source: Author calculation, based on data from Table 14

Table 49: 2020 exchange rate data in differences with standard deviation (σ)

σ	1.897151463	0	0.2	1	4.3	0.6	1.1	0.8
Exchange	**Country**	BG	CZ	HR	HU	PL	RO	SE
0	Bulgaria	0	-0.2	-1	-4.3	-0.6	-1.1	-0.8
0.2	Czechia	0.2	0	-0.8	-4.1	-0.4	-0.9	-0.6
1	Croatia	1	0.8	0	-3.3	0.4	-0.1	0.2
4.3	Hungary	4.3	4.1	3.3	0	3.7	3.2	3.5
0.6	Poland	0.6	0.4	-0.4	-3.7	0	-0.5	-0.2
1.1	Romania	1.1	0.9	0.1	-3.2	0.5	0	0.3
0.8	Sweden	0.8	0.6	-0.2	-3.5	0.2	-0.3	0

Source: Author calculation, based on data from Table 14

Table 50: 2020 exchange rate data normalized by dividing it by its standard deviation

Debt	BG	CZ	HR	HU	PL	RO	SE
Bulgaria	0.000	-0.105	-0.527	-2.267	-0.316	-0.580	-0.422
Czechia	0.105	0.000	-0.422	-2.161	-0.211	-0.474	-0.316
Croatia	0.527	0.422	0.000	-1.739	0.211	-0.053	0.105
Hungary	2.267	2.161	1.739	0.000	1.950	1.687	1.845
Poland	0.316	0.211	-0.211	-1.950	0.000	-0.264	-0.105
Romania	0.580	0.474	0.053	-1.687	0.264	0.000	0.158
Sweden	0.422	0.316	-0.105	-1.845	0.105	-0.158	0.000

Source: Author calculation, based on data from Table 14

Appendix B – Criteria tables for 2010 data

Table 51: 2010 inflation rate data in differences with standard deviation (σ)

σ	2.756003548	1.7	0.3	-0.7	0.1	2	4.8	3.9	5	2.1
Inflation	**Country**	BG	CZ	EE	LV	LT	HU	PL	RO	SE
1.7	Bulgaria	0	1.4	2.4	1.6	-0.3	-3.1	-2.2	-3.3	-0.4
0.3	Czechia	-1.4	0	1	0.2	-1.7	-4.5	-3.6	-4.7	-1.8
-0.7	Estonia	-2.4	-1	0	-0.8	-2.7	-5.5	-4.6	-5.7	-2.8
0.1	Latvia	-1.6	-0.2	0.8	0	-1.9	-4.7	-3.8	-4.9	-2
2	Lithuania	0.3	1.7	2.7	1.9	0	-2.8	-1.9	-3	-0.1
4.8	Hungary	3.1	4.5	5.5	4.7	2.8	0	0.9	-0.2	2.7
3.9	Poland	2.2	3.6	4.6	3.8	1.9	-0.9	0	-1.1	1.8
5	Romania	3.3	4.7	5.7	4.9	3	0.2	1.1	0	2.9
2.1	Sweden	0.4	1.8	2.8	2	0.1	-2.7	-1.8	-2.9	0

Source: Author calculation, based on data from Table 27

Table 52: 2010 inflation rate data normalized by dividing it by its standard deviation

Inflation	BG	CZ	EE	LV	LT	HU	PL	RO	SE
Bulgaria	0.000	0.508	0.871	0.581	-0.109	-1.125	-0.798	-1.197	-0.145
Czechia	-0.508	0.000	0.363	0.073	-0.617	-1.633	-1.306	-1.705	-0.653
Estonia	-0.871	-0.363	0.000	-0.290	-0.980	-1.996	-1.669	-2.068	-1.016
Latvia	-0.581	-0.073	0.290	0.000	-0.689	-1.705	-1.379	-1.778	-0.726
Lithuania	0.109	0.617	0.980	0.689	0.000	-1.016	-0.689	-1.089	-0.036
Hungary	1.125	1.633	1.996	1.705	1.016	0.000	0.327	-0.073	0.980
Poland	0.798	1.306	1.669	1.379	0.689	-0.327	0.000	-0.399	0.653
Romania	1.197	1.705	2.068	1.778	1.089	0.073	0.399	0.000	1.052
Sweden	0.145	0.653	1.016	0.726	0.036	-0.980	-0.653	-1.052	0.000

Source: Author calculation, based on data from Table 27

Table 53: 2010 deficit ratio data in differences with standard deviation (σ)

σ	3.589146878	2.8	5.7	2.4	8.6	8.4	4.1	7.3	8	2.1
Deficit	**Country**	BG	CZ	EE	LV	LT	HU	PL	RO	SE
2.8	Bulgaria	0	-2.9	0.4	-5.8	-5.6	-1.3	-4.5	-5.2	0.7
5.7	Czechia	2.9	0	3.3	-2.9	-2.7	1.6	-1.6	-2.3	3.6
2.4	Estonia	-0.4	-3.3	0	-6.2	-6	-1.7	-4.9	-5.6	0.3
8.6	Latvia	5.8	2.9	6.2	0	0.2	4.5	1.3	0.6	6.5
8.4	Lithuania	5.6	2.7	6	-0.2	0	4.3	1.1	0.4	6.3
4.1	Hungary	1.3	-1.6	1.7	-4.5	-4.3	0	-3.2	-3.9	2
7.3	Poland	4.5	1.6	4.9	-1.3	-1.1	3.2	0	-0.7	5.2
8	Romania	5.2	2.3	5.6	-0.6	-0.4	3.9	0.7	0	5.9
2.1	Sweden	-0.7	-3.6	-0.3	-6.5	-6.3	-2	-5.2	-5.9	0

Source: Author calculation, based on data from Table 27

Table 54: 2010 deficit ratio data normalized by dividing it by its standard deviation

Deficit	BG	CZ	EE	LV	LT	HU	PL	RO	SE
Bulgaria	0.000	-0.808	0.111	-1.616	-1.560	-0.362	-1.254	-1.449	0.195
Czechia	0.808	0.000	0.919	-0.808	-0.752	0.446	-0.446	-0.641	1.003
Estonia	-0.111	-0.919	0.000	-1.727	-1.672	-0.474	-1.365	-1.560	0.084
Latvia	1.616	0.808	1.727	0.000	0.056	1.254	0.362	0.167	1.811
Lithuania	1.560	0.752	1.672	-0.056	0.000	1.198	0.306	0.111	1.755
Hungary	0.362	-0.446	0.474	-1.254	-1.198	0.000	-0.892	-1.087	0.557
Poland	1.254	0.446	1.365	-0.362	-0.306	0.892	0.000	-0.195	1.449
Romania	1.449	0.641	1.560	-0.167	-0.111	1.087	0.195	0.000	1.644
Sweden	-0.195	-1.003	-0.084	-1.811	-1.755	-0.557	-1.449	-1.644	0.000

Source: Author calculation, based on data from Table 27

Table 55: 2010 debt ratio data in differences with standard deviation (σ)

σ	27.13175899	17.4	39.8	9.6	48.5	38.6	78.9	53.9	30.5	42.6
Debt	**Country**	BG	CZ	EE	LV	LT	HU	PL	RO	SE
17.4	Bulgaria	0	-22.4	7.8	-31.1	-21.2	-61.5	-36.5	-13.1	-25.2
39.8	Czechia	22.4	0	30.2	-8.7	1.2	-39.1	-14.1	9.3	-2.8
9.6	Estonia	-7.8	-30.2	0	-38.9	-29	-69.3	-44.3	-20.9	-33
48.5	Latvia	31.1	8.7	38.9	0	9.9	-30.4	-5.4	18	5.9
38.6	Lithuania	21.2	-1.2	29	-9.9	0	-40.3	-15.3	8.1	-4
78.9	Hungary	61.5	39.1	69.3	30.4	40.3	0	25	48.4	36.3
53.9	Poland	36.5	14.1	44.3	5.4	15.3	-25	0	23.4	11.3
30.5	Romania	13.1	-9.3	20.9	-18	-8.1	-48.4	-23.4	0	-12.1
42.6	Sweden	25.2	2.8	33	-5.9	4	-36.3	-11.3	12.1	0

Source: Author calculation, based on data from Table 27

Table 56: 2010 debt ratio data normalized by dividing it by its standard deviation

Debt	BG	CZ	EE	LV	LT	HU	PL	RO	SE
Bulgaria	0.000	-0.826	0.287	-1.146	-0.781	-2.267	-1.345	-0.483	-0.929
Czechia	0.826	0.000	1.113	-0.321	0.044	-1.441	-0.520	0.343	-0.103
Estonia	-0.287	-1.113	0.000	-1.434	-1.069	-2.554	-1.633	-0.770	-1.216
Latvia	1.146	0.321	1.434	0.000	0.365	-1.120	-0.199	0.663	0.217
Lithuania	0.781	-0.044	1.069	-0.365	0.000	-1.485	-0.564	0.299	-0.147
Hungary	2.267	1.441	2.554	1.120	1.485	0.000	0.921	1.784	1.338
Poland	1.345	0.520	1.633	0.199	0.564	-0.921	0.000	0.862	0.416
Romania	0.483	-0.343	0.770	-0.663	-0.299	-1.784	-0.862	0.000	-0.446
Sweden	0.929	0.103	1.216	-0.217	0.147	-1.338	-0.416	0.446	0.000

Source: Author calculation, based on data from Table 27

Table 57: 2010 exchange rate data in differences with standard deviation (σ)

σ	4.20481793	0	2.6	0	0.4	0	4.5	8.4	2.9	6.8
Exchange	**Country**	BG	CZ	EE	LV	LT	HU	PL	RO	SE
0	Bulgaria	0	-2.6	0	-0.4	0	-4.5	-8.4	-2.9	-6.8
2.6	Czechia	2.6	0	2.6	2.2	2.6	-1.9	-5.8	-0.3	-4.2
0	Estonia	0	-2.6	0	-0.4	0	-4.5	-8.4	-2.9	-6.8
0.4	Latvia	0.4	-2.2	0.4	0	0.4	-4.1	-8	-2.5	-6.4
0	Lithuania	0	-2.6	0	-0.4	0	-4.5	-8.4	-2.9	-6.8
4.5	Hungary	4.5	1.9	4.5	4.1	4.5	0	-3.9	1.6	-2.3
8.4	Poland	8.4	5.8	8.4	8	8.4	3.9	0	5.5	1.6
2.9	Romania	2.9	0.3	2.9	2.5	2.9	-1.6	-5.5	0	-3.9
6.8	Sweden	6.8	4.2	6.8	6.4	6.8	2.3	-1.6	3.9	0

Source: Author calculation, based on data from Table 27

Table 58: 2010 exchange rate data normalized by dividing it by its standard deviation

Exchange	BG	CZ	EE	LV	LT	HU	PL	RO	SE
Bulgaria	0.000	-0.618	0.000	-0.095	0.000	-1.070	-1.998	-0.690	-1.617
Czechia	0.618	0.000	0.618	0.523	0.618	-0.452	-1.379	-0.071	-0.999
Estonia	0.000	-0.618	0.000	-0.095	0.000	-1.070	-1.998	-0.690	-1.617
Latvia	0.095	-0.523	0.095	0.000	0.095	-0.975	-1.903	-0.595	-1.522
Lithuania	0.000	-0.618	0.000	-0.095	0.000	-1.070	-1.998	-0.690	-1.617
Hungary	1.070	0.452	1.070	0.975	1.070	0.000	-0.928	0.381	-0.547
Poland	1.998	1.379	1.998	1.903	1.998	0.928	0.000	1.308	0.381
Romania	0.690	0.071	0.690	0.595	0.690	-0.381	-1.308	0.000	-0.928
Sweden	1.617	0.999	1.617	1.522	1.617	0.547	-0.381	0.928	0.000

Source: Author calculation, based on data from Table 27

Table 59: 2010 interest rate data in differences with standard deviation (σ)

σ	5.227703979	6.9	4.7	15**	12.7	12.1	8.4	6.1	9.4	3.3
Interest	**Country**	BG	CZ	EE**	LV	LT	HU	PL	RO	SE
6.9	Bulgaria	0	2.2	-8.1	-5.8	-5.2	-1.5	0.8	-2.5	3.6
4.7	Czechia	-2.2	0	-10.3	-8	-7.4	-3.7	-1.4	-4.7	1.4
15**	Estonia**	8.1	10.3	0	2.3	2.9	6.6	8.9	5.6	11.7
12.7	Latvia	5.8	8	-2.3	0	0.6	4.3	6.6	3.3	9.4
12.1	Lithuania	5.2	7.4	-2.9	-0.6	0	3.7	6	2.7	8.8
8.4	Hungary	1.5	3.7	-6.6	-4.3	-3.7	0	2.3	-1	5.1
6.1	Poland	-0.8	1.4	-8.9	-6.6	-6	-2.3	0	-3.3	2.8
9.4	Romania	2.5	4.7	-5.6	-3.3	-2.7	1	3.3	0	6.1
3.3	Sweden	-3.6	-1.4	-11.7	-9.4	-8.8	-5.1	-2.8	-6.1	0

Source: Author calculation, based on data from Table 27

Table 60: 2010 interest rate data normalized by dividing it by its standard deviation

Interest	BG	CZ	EE**	LV	LT	HU	PL	RO	SE
Bulgaria	0.000	0.421	-1.549	-1.109	-0.995	-0.287	0.153	-0.478	0.689
Czechia	-0.421	0.000	-1.970	-1.530	-1.416	-0.708	-0.268	-0.899	0.268
Estonia**	1.549	1.970	0.000	0.440	0.555	1.263	1.702	1.071	2.238
Latvia	1.109	1.530	-0.440	0.000	0.115	0.823	1.263	0.631	1.798
Lithuania	0.995	1.416	-0.555	-0.115	0.000	0.708	1.148	0.516	1.683
Hungary	0.287	0.708	-1.263	-0.823	-0.708	0.000	0.440	-0.191	0.976
Poland	-0.153	0.268	-1.702	-1.263	-1.148	-0.440	0.000	-0.631	0.536
Romania	0.478	0.899	-1.071	-0.631	-0.516	0.191	0.631	0.000	1.167
Sweden	-0.689	-0.268	-2.238	-1.798	-1.683	-0.976	-0.536	-1.167	0.000

Source: Author calculation, based on data from Table 27

Appendix C – Criteria tables for 2004 data

Table 61: 2004 inflation rate data in differences with standard deviation (σ)

σ	3.362948333	1.8	2	2.1	4.9	-0.2	6.5	2.6	2.5	4.1	8.4	1.3
Inflation	**Country**	CZ	EE	CY	LV	LT	HU	MT	PL	SI	SK	SE
1.8	Czechia	0	-0.2	-0.3	-3.1	2	-4.7	-0.8	-0.7	-2.3	-6.6	0.5
2	Estonia	0.2	0	-0.1	-2.9	2.2	-4.5	-0.6	-0.5	-2.1	-6.4	0.7
2.1	Cyprus	0.3	0.1	0	-2.8	2.3	-4.4	-0.5	-0.4	-2	-6.3	0.8
4.9	Latvia	3.1	2.9	2.8	0	5.1	-1.6	2.3	2.4	0.8	-3.5	3.6
-0.2	Lithuania	-2	-2.2	-2.3	-5.1	0	-6.7	-2.8	-2.7	-4.3	-8.6	-1.5
6.5	Hungary	4.7	4.5	4.4	1.6	6.7	0	3.9	4	2.4	-1.9	5.2
2.6	Malta	0.8	0.6	0.5	-2.3	2.8	-3.9	0	0.1	-1.5	-5.8	1.3
2.5	Poland	0.7	0.5	0.4	-2.4	2.7	-4	-0.1	0	-1.6	-5.9	1.2
4.1	Slovenia	2.3	2.1	2	-0.8	4.3	-2.4	1.5	1.6	0	-4.3	2.8
8.4	Slovakia	6.6	6.4	6.3	3.5	8.6	1.9	5.8	5.9	4.3	0	7.1
1.3	Sweden	-0.5	-0.7	-0.8	-3.6	1.5	-5.2	-1.3	-1.2	-2.8	-7.1	0

Source: Author calculation, based on data from Table 35

Table 62: 2004 inflation rate data normalized by dividing it by its standard deviation

Inflation	CZ	EE	CY	LV	LT	HU	MT	PL	SI	SK	SE
Czechia	0.000	-0.059	-0.089	-0.922	0.595	-1.398	-0.238	-0.208	-0.684	-1.963	0.149
Estonia	0.059	0.000	-0.030	-0.862	0.654	-1.338	-0.178	-0.149	-0.624	-1.903	0.208
Cyprus	0.089	0.030	0.000	-0.833	0.684	-1.308	-0.149	-0.119	-0.595	-1.873	0.238
Latvia	0.922	0.862	0.833	0.000	1.517	-0.476	0.684	0.714	0.238	-1.041	1.070
Lithuania	-0.595	-0.654	-0.684	-1.517	0.000	-1.992	-0.833	-0.803	-1.279	-2.557	-0.446
Hungary	1.398	1.338	1.308	0.476	1.992	0.000	1.160	1.189	0.714	-0.565	1.546
Malta	0.238	0.178	0.149	-0.684	0.833	-1.160	0.000	0.030	-0.446	-1.725	0.387
Poland	0.208	0.149	0.119	-0.714	0.803	-1.189	-0.030	0.000	-0.476	-1.754	0.357
Slovenia	0.684	0.624	0.595	-0.238	1.279	-0.714	0.446	0.476	0.000	-1.279	0.833
Slovakia	1.963	1.903	1.873	1.041	2.557	0.565	1.725	1.754	1.279	0.000	2.111
Sweden	-0.149	-0.208	-0.238	-1.070	0.446	-1.546	-0.387	-0.357	-0.833	-2.111	0.000

Source: Author calculation, based on data from Table 35

Table 63: 2004 deficit ratio data in differences with standard deviation (σ)

σ	3.073318932	5	-0.3	5.2	2	2.6	5.5	5.2	5.6	2.3	3.9	-0.6
Deficit	**Country**	CZ	EE	CY	LV	LT	HU	MT	PL	SI	SK	SE
5	Czechia	0	5.3	-0.2	3	2.4	-0.5	-0.2	-0.6	2.7	1.1	5.6
-0.3	Estonia	-5.3	0	-5.5	-2.3	-2.9	-5.8	-5.5	-5.9	-2.6	-4.2	0.3
5.2	Cyprus	0.2	5.5	0	3.2	2.6	-0.3	0	-0.4	2.9	1.3	5.8
2	Latvia	-3	2.3	-3.2	0	-0.6	-3.5	-3.2	-3.6	-0.3	-1.9	2.6
2.6	Lithuania	-2.4	2.9	-2.6	0.6	0	-2.9	-2.6	-3	0.3	-1.3	3.2
5.5	Hungary	0.5	5.8	0.3	3.5	2.9	0	0.3	-0.1	3.2	1.6	6.1
5.2	Malta	0.2	5.5	0	3.2	2.6	-0.3	0	-0.4	2.9	1.3	5.8
5.6	Poland	0.6	5.9	0.4	3.6	3	0.1	0.4	0	3.3	1.7	6.2
2.3	Slovenia	-2.7	2.6	-2.9	0.3	-0.3	-3.2	-2.9	-3.3	0	-1.6	2.9
3.9	Slovakia	-1.1	4.2	-1.3	1.9	1.3	-1.6	-1.3	-1.7	1.6	0	4.5
-0.6	Sweden	-5.6	-0.3	-5.8	-2.6	-3.2	-6.1	-5.8	-6.2	-2.9	-4.5	0

Source: Author calculation, based on data from Table 35

Table 64: 2004 deficit ratio data normalized by dividing it by its standard deviation

Deficit	CZ	EE	CY	LV	LT	HU	MT	PL	SI	SK	SE
Czechia	0.000	1.725	-0.065	0.976	0.781	-0.163	-0.065	-0.195	0.879	0.358	1.822
Estonia	-1.725	0.000	-1.790	-0.748	-0.944	-1.887	-1.790	-1.920	-0.846	-1.367	0.098
Cyprus	0.065	1.790	0.000	1.041	0.846	-0.098	0.000	-0.130	0.944	0.423	1.887
Latvia	-0.976	0.748	-1.041	0.000	-0.195	-1.139	-1.041	-1.171	-0.098	-0.618	0.846
Lithuania	-0.781	0.944	-0.846	0.195	0.000	-0.944	-0.846	-0.976	0.098	-0.423	1.041
Hungary	0.163	1.887	0.098	1.139	0.944	0.000	0.098	-0.033	1.041	0.521	1.985
Malta	0.065	1.790	0.000	1.041	0.846	-0.098	0.000	-0.130	0.944	0.423	1.887
Poland	0.195	1.920	0.130	1.171	0.976	0.033	0.130	0.000	1.074	0.553	2.017
Slovenia	-0.879	0.846	-0.944	0.098	-0.098	-1.041	-0.944	-1.074	0.000	-0.521	0.944
Slovakia	-0.358	1.367	-0.423	0.618	0.423	-0.521	-0.423	-0.553	0.521	0.000	1.464
Sweden	-1.822	-0.098	-1.887	-0.846	-1.041	-1.985	-1.887	-2.017	-0.944	-1.464	0.000

Source: Author calculation, based on data from Table 35

Table 65: 2004 debt ratio data in differences with standard deviation (σ)

σ	30.41676354	37.9	4.8	72.6	14.7	21.4	59.9	73.8	47.2	30.8	44.5	51.6
Debt	**Country**	CZ	EE	CY	LV	LT	HU	MT	PL	SI	SK	SE
37.9	Czechia	0	33.1	-34.7	23.2	16.5	-22	-35.9	-9.3	7.1	-6.6	-13.7
4.8	Estonia	-33.1	0	-67.8	-9.9	-16.6	-55.1	-69	-42.4	-26	-39.7	-46.8
72.6	Cyprus	34.7	67.8	0	57.9	51.2	12.7	-1.2	25.4	41.8	28.1	21
14.7	Latvia	-23.2	9.9	-57.9	0	-6.7	-45.2	-59.1	-32.5	-16.1	-29.8	-36.9
21.4	Lithuania	-16.5	16.6	-51.2	6.7	0	-38.5	-52.4	-25.8	-9.4	-23.1	-30.2
59.9	Hungary	22	55.1	-12.7	45.2	38.5	0	-13.9	12.7	29.1	15.4	8.3
73.8	Malta	35.9	69	1.2	59.1	52.4	13.9	0	26.6	43	29.3	22.2
47.2	Poland	9.3	42.4	-25.4	32.5	25.8	-12.7	-26.6	0	16.4	2.7	-4.4
30.8	Slovenia	-7.1	26	-41.8	16.1	9.4	-29.1	-43	-16.4	0	-13.7	-20.8
44.5	Slovakia	6.6	39.7	-28.1	29.8	23.1	-15.4	-29.3	-2.7	13.7	0	-7.1
51.6	Sweden	13.7	46.8	-21	36.9	30.2	-8.3	-22.2	4.4	20.8	7.1	0

Source: Author calculation, based on data from Table 35

Table 66: 2004 debt ratio data normalized by dividing it by its standard deviation

Debt	CZ	EE	CY	LV	LT	HU	MT	PL	SI	SK	SE
Czechia	0.000	1.088	-1.141	0.763	0.542	-0.723	-1.180	-0.306	0.233	-0.217	-0.450
Estonia	-1.088	0.000	-2.229	-0.325	-0.546	-1.812	-2.268	-1.394	-0.855	-1.305	-1.539
Cyprus	1.141	2.229	0.000	1.904	1.683	0.418	-0.039	0.835	1.374	0.924	0.690
Latvia	-0.763	0.325	-1.904	0.000	-0.220	-1.486	-1.943	-1.068	-0.529	-0.980	-1.213
Lithuania	-0.542	0.546	-1.683	0.220	0.000	-1.266	-1.723	-0.848	-0.309	-0.759	-0.993
Hungary	0.723	1.812	-0.418	1.486	1.266	0.000	-0.457	0.418	0.957	0.506	0.273
Malta	1.180	2.268	0.039	1.943	1.723	0.457	0.000	0.875	1.414	0.963	0.730
Poland	0.306	1.394	-0.835	1.068	0.848	-0.418	-0.875	0.000	0.539	0.089	-0.145
Slovenia	-0.233	0.855	-1.374	0.529	0.309	-0.957	-1.414	-0.539	0.000	-0.450	-0.684
Slovakia	0.217	1.305	-0.924	0.980	0.759	-0.506	-0.963	-0.089	0.450	0.000	-0.233
Sweden	0.450	1.539	-0.690	1.213	0.993	-0.273	-0.730	0.145	0.684	0.233	0.000

Source: Author calculation, based on data from Table 35

Table 67: 2004 interest rate data in differences with standard deviation (σ)

σ	2.366711287	4.7	10**	5.2	5	4.7	8.1	4.7	6.9	5.2	5.1	4.7
Interest	**Country**	CZ	EE**	CY	LV	LT	HU	MT	PL	SI	SK	SE
4.7	Czechia	0	-5.3	-0.5	-0.3	0	-3.4	0	-2.2	-0.5	-0.4	0
10**	Estonia**	5.3	0	4.8	5	5.3	1.9	5.3	3.1	4.8	4.9	5.3
5.2	Cyprus	0.5	-4.8	0	0.2	0.5	-2.9	0.5	-1.7	0	0.1	0.5
5	Latvia	0.3	-5	-0.2	0	0.3	-3.1	0.3	-1.9	-0.2	-0.1	0.3
4.7	Lithuania	0	-5.3	-0.5	-0.3	0	-3.4	0	-2.2	-0.5	-0.4	0
8.1	Hungary	3.4	-1.9	2.9	3.1	3.4	0	3.4	1.2	2.9	3	3.4
4.7	Malta	0	-5.3	-0.5	-0.3	0	-3.4	0	-2.2	-0.5	-0.4	0
6.9	Poland	2.2	-3.1	1.7	1.9	2.2	-1.2	2.2	0	1.7	1.8	2.2
5.2	Slovenia	0.5	-4.8	0	0.2	0.5	-2.9	0.5	-1.7	0	0.1	0.5
5.1	Slovakia	0.4	-4.9	-0.1	0.1	0.4	-3	0.4	-1.8	-0.1	0	0.4
4.7	Sweden	0	-5.3	-0.5	-0.3	0	-3.4	0	-2.2	-0.5	-0.4	0

Source: Author calculation, based on data from Table 35

Table 68: 2004 interest rate data normalized by dividing it by its standard deviation

Interest	CZ	EE**	CY	LV	LT	HU	MT	PL	SI	SK	SE
Czechia	0.000	-2.239	-0.211	-0.127	0.000	-1.437	0.000	-0.930	-0.211	-0.169	0.000
Estonia**	2.239	0.000	2.028	2.113	2.239	0.803	2.239	1.310	2.028	2.070	2.239
Cyprus	0.211	-2.028	0.000	0.085	0.211	-1.225	0.211	-0.718	0.000	0.042	0.211
Latvia	0.127	-2.113	-0.085	0.000	0.127	-1.310	0.127	-0.803	-0.085	-0.042	0.127
Lithuania	0.000	-2.239	-0.211	-0.127	0.000	-1.437	0.000	-0.930	-0.211	-0.169	0.000
Hungary	1.437	-0.803	1.225	1.310	1.437	0.000	1.437	0.507	1.225	1.268	1.437
Malta	0.000	-2.239	-0.211	-0.127	0.000	-1.437	0.000	-0.930	-0.211	-0.169	0.000
Poland	0.930	-1.310	0.718	0.803	0.930	-0.507	0.930	0.000	0.718	0.761	0.930
Slovenia	0.211	-2.028	0.000	0.085	0.211	-1.225	0.211	-0.718	0.000	0.042	0.211
Slovakia	0.169	-2.070	-0.042	0.042	0.169	-1.268	0.169	-0.761	-0.042	0.000	0.169
Sweden	0.000	-2.239	-0.211	-0.127	0.000	-1.437	0.000	-0.930	-0.211	-0.169	0.000

Source: Author calculation, based on data from Table 35