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InterCriteria Decision Making Approach to EU Member States Competitiveness Analysis: Temporal and Threshold Analysis

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Abstract. In this paper, we present some interesting findings from the application of our recently developed InterCriteria Decision Making (ICDM) approach to data extracted from the World Economic Forum's Global Competitiveness Reports for the years 2008–2009 to 2013–2014 for the current 28 Member States of the European Union. The developed approach which employs the apparatuses of index matrices and intuitionistic fuzzy sets is designed to produce from an existing index matrix with multiobject multicriteria evaluations a new index matrix that contains intuitionistic fuzzy pairs with the correlations revealed to exist in between the set of evaluation criteria, which are not obligatory there 'by design' of the WEF's methodology but exist due to the integral, organic nature of economic data. Here, we analyse the data from the six-year period within a reasonably chosen intervals for the thresholds of the intuitionistic fuzzy functions of membership and non-membership, and make a series of observations about the current trends in the factors of competitiveness of the European Union. The whole research and the conclusions derived are in line with WEF's address to state policy makers to identify and strengthen the transformative forces that will drive future economic growth.

Keywords: Global Competitiveness Index, Index matrix, InterCriteria decision making, Intuitionistic fuzzy sets, Multicriteria decision making.

1 Introduction

The present work contains a continuation of our recent research, started in [7], which aims at analyzing data about the performance of the 28 European Union Member

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States according to the Global Competitiveness Reports (GCRs) of the World Economic Forum (WEF), released in the period from 2008–2009 to 2013–2014. We use a recently developed multicriteria decision making method, based on intuitionistic fuzzy sets and index matrices, two mathematical formalisms proposed and significantly researched by Atanassov in a series of publications from 1980s to present day. As its title, InterCriteria Decision Making (ICDM, see [6]), suggests, the method aims at discovery of existing dependences *between* the evaluation criteria themselves.

The ICDM approach has been originally devised to reflect situations where some of the criteria come at a higher cost than others, for instance are harder, more expensive and/or more time consuming to measure or evaluate. Such criteria are generally considered unfavourable, hence if the method identifies certain level of correlation between such unfavourable criteria and others that are easier, cheaper or quicker to measure or evaluate, the unfavourable ones might be disregarded in the further decision making process.

In our work for applying ICDM to WEF GCR data [7] we have been interested to detect the eventual correlations between the 12 'pillars of country competitiveness', in order to outline fewer pillars on which policy makers should concentrate their efforts. Our motivation to conduct the analysis has been that it might be expected that improved country's performance against some pillars would positively affect the country's performance in the respective correlating ones. This is in line with WEF's address to state policy makers to identify and strengthen the transformative forces that will drive future economic growth of the countries, as formulated in the Preface of the latest Global Competitiveness Report 2013–2014, [8].

The twelve pillars in the WEF's methodology are grouped in three subindices:

- The first subindex 'Basic requirements' contains pillars 1–4: '1. Institutions', '2. Infrastructure', '3. Macroeconomic stability' and '4. Health and primary education', 25% weight for each pillar.
- The second subindex 'Efficiency enhancers' contains pillars 5–10: '5. Higher education and training', '6. Goods market efficiency', '7. Labor market efficiency', '8. Financial market sophistication', '9. Technological readiness' and '10. Market size', 17% weight for each pillar.
- The third subindex 'Innovation and sophistication factors' contains pillars 11–12: '11. Business sophistication' and '12. Innovation', 50% weight for each pillar.

On the basis of the evaluation of the countries according to these pillars and following a sophisticated methodology, WEF determines their 'stage of development', which is one of the five possible alternatives: '1. Factor driven', 'Transition 1–2', '2. Efficiency driven', 'Transition 2–3' or '3. Innovation driven'. From the 28 EU Member States, 19 are in stage '3. Innovation driven', 7 are in stage 'Transition 2–3', and 2 are in stage '2. Efficiency driven'.

In the first part of our research [7], we gave the comparison of the results of the ICDM for the two extreme years in the 6-year period, and discussed in more details the findings for the year 2013–2014. We showed the principle of gradual discovery of more correlations between the criteria by letting the two user defined thresholds involved in the ICDM approach change within the [0; 1]-interval. Example was given with a detailed description of the correlations in one partial case, and it was visually interpreted as a graph. Here, we will continue investigating the same selection of data, but we will further show how for each year, and for each pair of thresholds, the number of positive consonances for each of the twelve pillars change, and will accompany these observations with some initial conclusions.

This paper is organized as follows. In Section 2 the two basic mathematical concepts that we use – intuitionistic fuzzy sets and index matrices – are briefly presented and on this basis is described, the proposed method ICDM. Section 3 contains our results from applying the method to analysis of a selection of data about the performance of the currently 28 Member States of the EU during the last six years against the twelve pillars of competitiveness. We report the findings of our temporal and threshold analysis, and formulate our conclusions in the last Section 4.

2 Basic Concepts and Method

The presented multicriteria decision making method is based on two fundamental concepts: intuitionistic fuzzy sets and index matrices.

Intuitionistic fuzzy sets defined by Atanassov (cf. [1, 2, 4, 5]) represent an extension of the concept of fuzzy sets, as defined by Zadeh [9], exhibiting function $\mu_A(x)$ defining the membership of an element x to the set A, evaluated in the [0; 1]-interval. The difference between fuzzy sets and intuitionistic fuzzy sets (IFSs) is in the presence of a second function $\nu_A(x)$ defining the non-membership of the element x to the set A, where $\mu_A(x) \in [0; 1]$, $\nu_A(x) \in [0; 1]$, and moreover $(\mu_A(x) + \nu_A(x)) \in [0; 1]$.

The IFS itself is formally denoted by:

$$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle \mid x \in E\}.$$

Comparison between elements of any two IFSs, say A and B, involves pairwise comparisons between their respective elements' degrees of membership and non-membership to both sets.

The second concept on which the proposed method relies is the concept of index matrix, a matrix which features two index sets. The theory behind the index matrices is described in [3]. Here we will start with the index matrix M with index sets with m rows $\{C_1, \ldots, C_m\}$ and n columns $\{O_1, \ldots, O_n\}$:

$$M = \begin{array}{c|ccccccc}
 & O_1 & \cdots & O_k & \cdots & O_l & \cdots & O_n \\
\hline
C_1 & a_{C_1,O_1} & \cdots & a_{C_1,O_k} & \cdots & a_{C_1,O_l} & \cdots & a_{C_1,O_n} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
C_i & a_{C_i,O_1} & \cdots & a_{C_i,O_k} & \cdots & a_{C_i,O_l} & \cdots & a_{C_i,O_n} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
C_j & a_{C_j,O_1} & \cdots & a_{C_j,O_k} & \cdots & a_{C_j,O_l} & \cdots & a_{C_j,O_n} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
C_m & a_{C_m,O_1} & \cdots & a_{C_m,O_j} & \cdots & a_{C_m,O_l} & \cdots & a_{C_m,O_n}
\end{array},$$

where for every p, q ($1 \leq p \leq m$, $1 \leq q \leq n$), C_p is a criterion (in our case, one of the twelve pillars), O_q in an evaluated object (in our case, one of the 28 EU Member states), $a_{C_pO_q}$ is the evaluation of the q-th object against the p-th criterion, and it is defined as a real number or another object that is comparable according to relation R with all the rest elements of the index matrix M, so that for each i, j, k it holds the relation $R(a_{C_kO_i}, a_{C_kO_j})$. The relation R has dual relation $\overline{R}$, which is true in the cases when relation R is false, and vice versa.

For the needs of our decision making method, pairwise comparisons between every two different criteria are made along all evaluated objects. During the comparison, it is maintained one counter of the number of times when the relation R holds, and another counter for the dual relation.

Let $S^{\mu}_{k,l}$ be the number of cases where the relations $R(a_{C_kO_i}, a_{C_kO_j})$ and $R(a_{C_lO_i}, a_{C_lO_j})$ are simultaneously satisfied. Let also $S^{\nu}_{k,l}$ be the number of cases in which the relations $R(a_{C_kO_i}, a_{C_kO_j})$ and its dual $\overline{R}$ $(a_{C_lO_i}, a_{C_lO_j})$ are simultaneously satisfied. As the total number of pairwise comparisons between the object is $n(n-1)/2$, it is seen that there hold the inequalities:

$$0 \leq S^{\mu}_{k,l} + S^{\nu}_{k,l} \leq \frac{n(n-1)}{2}.$$

For every k, l, such that $1 \leq k \leq l \leq m$, and for $n \geq 2$ two numbers are defined:

$$\mu_{C_k,C_l} = 2\frac{S^{\mu}_{k,l}}{n(n-1)},\ \nu_{C_k,C_l} = 2\frac{S^{\nu}_{k,l}}{n(n-1)}.$$

The pair constructed from these two numbers plays the role of the intuitionistic fuzzy evaluation of the relations that can be established between any two criteria C_k and C_l. In this way the index matrix M that relates evaluated objects with evaluating criteria can be transformed to another index matrix M^* that gives the relations among the criteria:

$$M^* = \begin{array}{c|ccc} & C_1 & \cdots & C_m \\ \hline C_1 & \langle \mu_{C_1,C_1}, \nu_{C_1,C_1} \rangle & \cdots & \langle \mu_{C_1,C_m}, \nu_{C_1,C_m} \rangle \\ \vdots & \vdots & \ddots & \vdots \\ C_m & \langle \mu_{C_m,C_1}, \nu_{C_1,C_m} \rangle & \cdots & \langle \mu_{C_m,C_m}, \nu_{C_m,C_m} \rangle \end{array}.$$

The final step of the algorithm is to determine the degrees of correlation between the criteria, depending on the user's choice of μ and ν. We call these correlations between the criteria: 'positive consonance', 'negative consonance' or 'dissonance'.

Let $\alpha, \beta \in [0; 1]$ be given, so that $\alpha + \beta \leq 1$. We say that criteria C_k and C_l are in:

- (α, β)-positive consonance, if $\mu_{C_k,C_l} > \alpha$ and $\nu_{C_k,C_l} < \beta$;
- (α, β)-negative consonance, if $\mu_{C_k,C_l} < \beta$ and $\nu_{C_k,C_l} > \alpha$;
- (α, β)-dissonance, otherwise.

Obviously, the larger α and/or the smaller β, the less number of criteria may be simultaneously connected with the relation of (α, β)-positive consonance. For practical purposes, it carries the most information when either the positive or the negative consonance is as large as possible, while the cases of dissonance are less informative and are skipped.

3 Main Results

We ran the described algorithm over a selection of data from last six WEF GCRs for the 28 (present) EU Member States from the period 2008–2009 to 2013–2014. The algorithm, as described in Section 2, produces the results with precision of 9 digits after the decimal point, however, we will use here precision of only 3 digits. From the six index matrices of data for 28 countries evaluated according to 12 pillars, we obtain six index matrices 12×12 for the intuitionistic fuzzy μ-function and six more index matrices 12×12 for the intuitionistic fuzzy ν-function. Obviously, in the first IM, along the main diagonal, $\mu_{C_k,C_k} = 1$, while in the second IM, along the main diagonal, $\nu_{C_k,C_k} = 0$, because naturally every pillar is in perfect positive consonance to itself. The sum of the values of the respective elements of the two IMs is generally:

$$0 \leq \mu_{C_k,C_l} + \nu_{C_k,C_l} \leq 1,$$

though in most cases it should be expected that this non-strict inequality is practically a strict one ($0 \leq \mu_{C_k,C_l} + \nu_{C_k,C_l} < 1$), thus leaving room for the complement to 1, that gives the measure of uncertainty.

Our aim will be to study how the positive consonance pairs of pillars behave over the considered 6-year period and for different runs of the values of the thresholds α, β. We focus on the positive consonances, although in a separate leg of research it might prove useful to focus on the negative ones, too. The study goes in two directions:

- how within a fixed year, changing the thresholds α, β changes the number of consonances formed for each of the twelve pillars, and
- how for a fixed pair of values of α, β these consonances change over time.

To start with, we will repeat from [7] the two 12×12 index matrices with the revealed intercriteria relations. Table 1 below gives the values of the intuitionistic fuzzy μ-function, and Table 2 gives the values of the intuitionistic fuzzy ν-function. Here, all cells are coloured in the greyscale, with the highest values coloured in the darkest shade of grey, while the lowest ones are coloured in white. Of course, every criteria perfectly correlates with itself, so for any i the value $\mu_{C_iC_i} = 1$, and $\nu_{C_iC_i} = \pi_{C_iC_i} = 0$. Also, the matrices are obviously symmetrical according to the main diagonals.

Table 1. Comparison of the calculated values of $\mu_{C_i C_j}$ for years 2008–2009 and 2013–2014

μ	1	2	3	4	5	6	7	8	9	10	11	12
1	1.000	0.844	0.685	0.757	0.788	0.833	0.603	0.828	0.823	0.497	0.794	0.802
2	0.844	1.000	0.627	0.751	0.749	0.743	0.529	0.741	0.775	0.582	0.831	0.807
3	0.685	0.627	1.000	0.616	0.638	0.664	0.653	0.648	0.693	0.434	0.651	0.667
4	0.757	0.751	0.616	1.000	0.780	0.720	0.550	0.704	0.725	0.524	0.765	0.772
5	0.788	0.749	0.638	0.780	1.000	0.746	0.622	0.728	0.757	0.558	0.767	0.796
6	0.833	0.743	0.664	0.720	0.746	1.000	0.627	0.817	0.802	0.505	0.786	0.765
7	0.603	0.529	0.653	0.550	0.622	0.627	1.000	0.664	0.611	0.389	0.563	0.590
8	0.828	0.741	0.648	0.704	0.728	0.817	0.664	1.000	0.820	0.476	0.733	0.751
9	0.823	0.775	0.693	0.725	0.757	0.802	0.611	0.820	1.000	0.548	0.817	0.815
10	0.497	0.582	0.434	0.524	0.558	0.505	0.389	0.476	0.548	1.000	0.648	0.601
11	0.794	0.831	0.651	0.765	0.767	0.786	0.563	0.733	0.817	0.648	1.000	0.860
12	0.802	0.807	0.667	0.772	0.796	0.765	0.590	0.751	0.815	0.601	0.860	1.000

μ	1	2	3	4	5	6	7	8	9	10	11	12
1	1.000	0.735	0.577	0.720	0.807	0.836	0.733	0.749	0.854	0.503	0.804	0.844
2	0.735	1.000	0.479	0.661	0.749	0.677	0.537	0.590	0.786	0.661	0.804	0.799
3	0.577	0.479	1.000	0.421	0.519	0.558	0.627	0.675	0.550	0.413	0.548	0.556
4	0.720	0.661	0.421	1.000	0.730	0.683	0.590	0.563	0.677	0.497	0.712	0.690
5	0.807	0.749	0.519	0.730	1.000	0.735	0.622	0.632	0.775	0.579	0.815	0.847
6	0.836	0.677	0.558	0.683	0.735	1.000	0.749	0.712	0.788	0.466	0.759	0.751
7	0.733	0.537	0.627	0.590	0.622	0.749	1.000	0.741	0.685	0.399	0.624	0.624
8	0.749	0.590	0.675	0.563	0.632	0.712	0.741	1.000	0.712	0.497	0.688	0.680
9	0.854	0.786	0.550	0.677	0.775	0.788	0.685	0.712	1.000	0.526	0.810	0.831
10	0.503	0.661	0.413	0.497	0.579	0.466	0.399	0.497	0.526	1.000	0.611	0.598
11	0.804	0.804	0.548	0.712	0.815	0.759	0.624	0.688	0.810	0.611	1.000	0.873
12	0.844	0.799	0.556	0.690	0.847	0.751	0.624	0.680	0.831	0.598	0.873	1.000

Table 2. Comparison of the calculated values of $\nu_{C_i C_j}$ for years 2008–2009 and 2013–2014

ν	1	2	3	4	5	6	7	8	9	10	11	12
1	0.000	0.114	0.241	0.140	0.140	0.077	0.275	0.116	0.116	0.458	0.148	0.127
2	0.114	0.000	0.304	0.156	0.190	0.167	0.365	0.220	0.180	0.384	0.127	0.138
3	0.241	0.304	0.000	0.265	0.265	0.209	0.204	0.270	0.225	0.495	0.270	0.241
4	0.140	0.156	0.265	0.000	0.108	0.140	0.294	0.201	0.169	0.381	0.138	0.111
5	0.140	0.190	0.265	0.108	0.000	0.135	0.233	0.198	0.164	0.378	0.156	0.130
6	0.077	0.167	0.209	0.140	0.135	0.000	0.209	0.090	0.095	0.397	0.114	0.127
7	0.275	0.365	0.204	0.294	0.233	0.209	0.000	0.212	0.259	0.497	0.315	0.265
8	0.116	0.220	0.270	0.201	0.198	0.090	0.212	0.000	0.132	0.476	0.217	0.196
9	0.116	0.180	0.225	0.169	0.164	0.095	0.259	0.132	0.000	0.399	0.122	0.116
10	0.458	0.384	0.495	0.381	0.378	0.397	0.497	0.476	0.399	0.000	0.307	0.336
11	0.148	0.127	0.270	0.138	0.156	0.114	0.315	0.217	0.122	0.307	0.000	0.079
12	0.127	0.138	0.241	0.111	0.130	0.127	0.265	0.196	0.116	0.336	0.079	0.000

ν	1	2	3	4	5	6	7	8	9	10	11	12
1	0.000	0.220	0.386	0.188	0.132	0.077	0.185	0.172	0.090	0.452	0.138	0.111
2	0.220	0.000	0.466	0.228	0.172	0.228	0.362	0.317	0.146	0.286	0.135	0.138
3	0.386	0.466	0.000	0.476	0.405	0.344	0.286	0.251	0.394	0.537	0.394	0.389
4	0.188	0.228	0.476	0.000	0.143	0.169	0.283	0.307	0.201	0.397	0.175	0.198
5	0.132	0.172	0.405	0.143	0.000	0.153	0.272	0.259	0.135	0.341	0.098	0.079
6	0.077	0.228	0.344	0.169	0.153	0.000	0.135	0.169	0.101	0.439	0.143	0.159
7	0.185	0.362	0.286	0.283	0.272	0.135	0.000	0.146	0.209	0.505	0.267	0.275
8	0.172	0.317	0.251	0.307	0.259	0.169	0.146	0.000	0.206	0.415	0.217	0.233
9	0.090	0.146	0.394	0.201	0.135	0.101	0.209	0.206	0.000	0.405	0.119	0.101
10	0.452	0.286	0.537	0.397	0.341	0.439	0.505	0.415	0.405	0.000	0.328	0.344
11	0.138	0.135	0.394	0.175	0.098	0.143	0.267	0.217	0.119	0.328	0.000	0.071
12	0.111	0.138	0.389	0.198	0.079	0.159	0.275	0.233	0.101	0.344	0.071	0.000

Case 1. Fixed years, changing thresholds α, β

In Tables 3–8, where α, β run from (0.7; 0.3) to (0.85; 0.15), for each pillar is given the number of the rest pillars, which it is in positive consonance with, as evaluated by $\mu_{C_k, C_l} > \alpha$ and $\nu_{C_k, C_l} < \beta$. We will note that we skip the columns for pillars '3. Macroeconomic stability' and '10. Market size', since both do not enter into positive consonance with any of the rest.

Table 3. Results for fixed year 2008–2009.

α	β	C_1	C_2	C_4	C_5	C_6	C_7	C_8	C_9	C_{11}	C_{12}	Rel	Uniq
0.85	0.15	0	0	0	0	0	0	0	0	1	1	1	2
0.825	0.175	3	2	0	0	1	0	1	0	2	1	5	6
0.8	0.2	5	3	0	0	3	0	3	5	3	4	13	7
0.775	0.225	7	4	1	3	4	0	3	6	5	5	19	9
0.75	0.25	8	8	5	7	6	0	4	7	7	8	30	9
0.725	0.275	8	8	5	8	7	0	7	7	8	8	33	9
0.7	0.3	8	8	8	8	8	0	8	8	8	8	36	9

Table 4. Results for fixed year 2009–2010.

α	β	C_1	C_2	C_4	C_5	C_6	C_7	C_8	C_9	C_{11}	C_{12}	Rel	Uniq
0.85	0.15	0	0	0	0	0	0	0	0	1	1	1	2
0.825	0.175	2	0	0	0	2	0	0	2	1	1	4	5
0.8	0.2	3	1	0	1	2	0	0	3	1	5	8	7
0.775	0.225	7	4	3	3	5	0	2	5	6	7	21	9
0.75	0.25	8	4	4	5	6	0	2	5	7	7	24	9
0.725	0.275	8	5	5	6	8	0	3	7	7	7	28	9
0.7	0.3	8	7	8	8	8	0	6	8	7	8	34	9

Table 5. Results for fixed year 2010–2011.

α	β	C_1	C_2	C_4	C_5	C_6	C_7	C_8	C_9	C_{11}	C_{12}	Rel	Uniq
0.85	0.15	0	0	0	0	0	0	0	0	1	1	1	2
0.825	0.175	3	0	0	0	1	0	0	1	1	2	4	5
0.8	0.2	5	2	0	2	1	0	0	2	3	5	10	7
0.775	0.225	5	3	0	2	4	0	0	5	5	6	15	7
0.75	0.25	6	4	1	3	5	0	0	5	6	6	18	8
0.725	0.275	6	4	3	5	6	0	0	6	7	7	22	8
0.7	0.3	8	5	5	7	7	0	2	6	7	7	27	9

Table 6. Results for fixed year 2011–2012.

α	β	C_1	C_2	C_4	C_5	C_6	C_7	C_8	C_9	C_{11}	C_{12}	Rel	Uniq
0.85	0.15	0	0	0	0	0	0	0	1	1	2	2	3
0.825	0.175	2	1	0	0	0	0	0	3	3	3	6	5
0.8	0.2	3	3	0	1	0	0	0	4	4	5	10	6
0.775	0.225	5	3	0	3	2	0	0	5	5	5	14	7
0.75	0.25	5	3	0	4	3	0	0	6	6	5	16	7
0.725	0.275	7	4	0	4	5	0	2	6	6	6	20	8
0.7	0.3	7	5	1	6	7	1	3	7	7	6	25	10

Table 7. Results for fixed year 2012–2013.

α	β	C_1	C_2	C_4	C_5	C_6	C_7	C_8	C_9	C_{11}	C_{12}	Rel	Uniq
0.85	0.15	0	0	0	0	0	0	0	1	1	2	2	3
0.825	0.175	3	0	0	0	1	0	0	3	2	4	7	5
0.8	0.2	5	1	0	2	2	0	0	4	4	4	11	7
0.775	0.225	5	3	0	4	2	0	0	6	5	5	15	7
0.75	0.25	5	3	0	4	3	0	0	6	6	5	16	7
0.725	0.275	8	5	1	7	6	2	3	6	6	6	25	10
0.7	0.3	9	5	6	7	8	3	4	8	7	7	32	10

Table 8. Results for fixed year 2013–2014.

α	β	C_1	C_2	C_4	C_5	C_6	C_7	C_8	C_9	C_{11}	C_{12}	Rel	Uniq
0.85	0.15	3	0	0	1	1	0	0	1	1	3	5	6
0.825	0.175	3	0	0	1	1	0	0	2	1	4	6	6
0.8	0.2	5	1	0	3	1	0	0	3	5	4	11	7
0.775	0.225	5	3	0	4	2	0	0	6	5	5	15	7
0.75	0.25	5	3	0	4	4	0	0	6	6	6	17	7
0.725	0.275	8	4	1	7	6	0	2	6	6	6	23	9
0.7	0.3	9	5	3	7	7	4	3	7	7	6	29	10

From the data in Tables 3–8, we can make some general observations concerning the thresholds α, β. These observations are needed for setting the general framework in which the findings of the present research can be usefully interpreted. Obviously, neither too few, nor too many correlating pillars would help yield an effective economic analysis.

- *Observation 1.* Three of the twelve pillars, namely, the basic requirement pillar '3. Macroeconomic stability' and the efficiency enhancer pillars '7. Labor market efficiency' and '10. Market size' tend to avoid positive consonances with the rest pillars in the WEF GCR methodology, which is especially well expressed for the 3rd and 10th pillars (for all studied years, the values of μ_{C_3,C_l} ranging from 0.648 to 0.693 and the maximal value of μ_{C_{10},C_l} ranging from 0.622 to 0.672). In general, it is worth analysing to what extent it is natural to have these pillars uncorrelated to the rest, or to what extent it results from particular governments' malperformance.
- *Observation 2.* Under a certain value for threshold α (respectively, above a certain value for threshold β), it is natural that all pillars start correlating, which is ineffective for the analysis. In the light of the Observation 1, we can safely focus only on the thresholds when the 9 out of 12 pillars start correlating, which is at $\alpha = 0.775$ for the first two years, and with α falling to around 0.725 in the next four years. Hence, it is interesting to analyse the data corresponding to larger values of threshold α.
- *Observation 3.* In the other extreme, analysing data for too few pillars being in positive consonance is not effective either. We observe that until 2013–2014, the number of unique correlating pillars when $\alpha = 0.85$ is 2 or 3 out of 12 (mainly '11. Business sophistication' and '12. Innovation', sometimes accompanied by the basic requirement pillar '1. Institutions'). The sudden number of six correlating pillars with as high threshold for α as 0.85 can be interpreted as a sign of raising mutual dependence of the different aspects of competitiveness, yet observations for next periods are needed for a more categorical conclusion.

Hence, it is most useful to focus the analysis in the range from (0.775; 0.225) to (0.825; 0.175). Besides the more general observations about the thresholds, we can also make some more specific observations about the pillars.

- *Observation 4.* The efficiency enhancer pillar '7. Labor market efficiency' starts correlating with the rest pillars only after year 2011–2012, and only in the low values of α from 0.7 to 0.75.
- *Observation 5.* The efficiency enhancer pillar '8. Financial market sophistication' in 2008–2009 and 2009–2010 was in consonance with other pillars as of $\alpha = 0.825$ or 0.775, respectively, after the α threshold for the 8th pillar falls down to $\alpha = 0.725$ and even 0.7, meaning that it becomes much weakly correlated.
- *Observation 6.* Pillars '11. Business sophistication' and '12. Innovation' have shown the greatest and most stable positive consonance between each other, as well as with the other pillars. This is not surprising, given that both pillars form with 50% weight each the third subindex 'Innovation and sophistication factors'.

Case 2. Fixed thresholds α, β, changing years

In the following temporal analysis (Tables 9–15) we compare how the pillars have correlated for the last six years at fixed values of the thresholds α, β.

Table 9. Results for fixed year $\alpha = 0.85$, $\beta = 0.15$.

Year	C_1	C_2	C_4	C_5	C_6	C_7	C_8	C_9	C_{11}	C_{12}	Rel	Uniq
2008–2009	0	0	0	0	0	0	0	0	1	1	1	2
2009–2010	0	0	0	0	0	0	0	0	1	1	1	2
2010–2011	0	0	0	0	0	0	0	0	1	1	1	2
2011–2012	0	0	0	0	0	0	0	1	1	2	2	3
2012–2013	0	0	0	0	0	0	0	1	1	2	2	3
2013–2014	3	0	0	1	1	0	0	1	1	3	5	6

Table 10. Results for fixed year $\alpha = 0.825$, $\beta = 0.175$.

Year	C_1	C_2	C_4	C_5	C_6	C_7	C_8	C_9	C_{11}	C_{12}	Rel	Uniq
2008–2009	3	2	0	0	1	0	1	0	2	1	5	6
2009–2010	2	0	0	0	2	0	0	2	1	1	4	5
2010–2011	3	0	0	0	1	0	0	1	1	2	4	5
2011–2012	2	1	0	0	0	0	0	3	3	3	6	5
2012–2013	3	0	0	0	1	0	0	3	2	4	7	5
2013–2014	3	0	0	1	1	0	0	2	1	4	6	6

Table 11. Results for fixed year $\alpha = 0.8$, $\beta = 0.2$.

Year	C_1	C_2	C_4	C_5	C_6	C_7	C_8	C_9	C_{11}	C_{12}	Rel	Uniq
2008–2009	5	3	0	0	3	0	3	5	3	4	13	7
2009–2010	3	1	0	1	2	0	0	3	1	5	8	7
2010–2011	5	2	0	2	1	0	0	2	3	5	10	7
2011–2012	3	3	0	1	0	0	0	4	4	5	10	6
2012–2013	5	1	0	2	2	0	0	4	4	4	11	7
2013–2014	5	1	0	3	1	0	0	3	5	4	11	7

Table 12. Results for fixed year $\alpha = 0.775$, $\beta = 0.225$.

Year	C_1	C_2	C_4	C_5	C_6	C_7	C_8	C_9	C_{11}	C_{12}	Rel	Uniq
2008–2009	7	4	1	3	4	0	3	6	5	5	19	9
2009–2010	7	4	3	3	5	0	2	5	6	7	21	9
2010–2011	5	3	0	2	4	0	0	5	5	6	15	7
2011–2012	5	3	0	3	2	0	0	5	5	5	14	7
2012–2013	5	3	0	4	2	0	0	6	5	5	15	7
2013–2014	5	3	0	4	2	0	0	6	5	5	15	7

Table 13. Results for fixed year $\alpha = 0.75$, $\beta = 0.25$

Year	C_1	C_2	C_4	C_5	C_6	C_7	C_8	C_9	C_{11}	C_{12}	Rel	Uniq
2008–2009	8	8	5	7	6	0	4	7	7	8	30	9
2009–2010	8	4	4	5	6	0	2	5	7	7	24	9
2010–2011	6	4	1	3	5	0	0	5	6	6	18	8
2011–2012	5	3	0	4	3	0	0	6	6	5	16	7
2012–2013	5	3	0	4	3	0	0	6	6	5	16	7
2013–2014	5	3	0	4	4	0	0	6	6	6	17	7

Table 14. Results for fixed year $\alpha = 0.725$, $\beta = 0.275$

Year	C_1	C_2	C_4	C_5	C_6	C_7	C_8	C_9	C_{11}	C_{12}	Rel	Uniq
2008–2009	8	8	5	8	7	0	7	7	8	8	33	9
2009–2010	8	5	5	6	8	0	3	7	7	7	28	9
2010–2011	6	4	3	5	6	0	0	6	7	7	22	8
2011–2012	7	4	0	4	5	0	2	6	6	6	20	8
2012–2013	8	5	1	7	6	2	3	6	6	6	25	10
2013–2014	8	4	1	7	6	0	2	6	6	6	23	9

Table 15. Results for fixed year $\alpha = 0.7$, $\beta = 0.3$

Year	C_1	C_2	C_4	C_5	C_6	C_7	C_8	C_9	C_{11}	C_{12}	Rel	Uniq
2008–2009	8	8	8	8	8	0	8	8	8	8	36	9
2009–2010	8	7	8	8	8	0	6	8	7	8	34	9
2010–2011	8	5	5	7	7	0	2	6	7	7	27	9
2011–2012	7	5	1	6	7	1	3	7	7	6	25	10
2012–2013	9	5	6	7	8	3	4	8	7	7	32	10
2013–2014	9	5	3	7	7	4	3	7	7	6	29	10

- *Observation 7.* We can observe that as of $\alpha = 0.85$, pillars 11 and 12 are again sustainably correlating during the whole period, and as of $\alpha = 0.825$ the basic requirement pillar '1. Institutions' also tends to enter in positive consonances, i.e. it is a factor of significant importance for the rest competitiveness pillars.
- *Observation 8.* With less but also visible importance are the efficiency enhancer pillars '9. Technological readiness' and '6. Goods market efficiency'.
- *Observation 9.* With (α; β) starting from (0.8; 0.2) down to (0.7; 0.3), we note that the number of positive consonances of the basic requirement pillar '2. Infrastructure' gradually reduces in time.

- *Observation 10.* We can also note that with the relatively high $\alpha > 0.75$, the efficiency enhancer pillar ‘8. Financial market sophistication’ has been in positive consonances only in the period 2008–2010, and for smaller α it has been visibly less correlated after 2010, than it was before.
- *Observation 11.* A very similar to observation to the previous one can also be made for the basic requirement pillar ‘4. Health and primary education’. Compared to it, the efficiency enhancer pillar ‘5. Higher education and training’ naturally shows higher levels of positive consonance with the rest competitiveness pillars for different runs of $(\alpha; \beta)$ throughout the whole period.
- *Observation 12.* The efficiency enhancer pillar ‘7. Labor market efficiency’ has only started exhibiting for $\alpha > 0.75$ and only in the last year.

Beyond these observations, a more detailed and profound analysis of these data should be done by economists, taking into consideration various factors like the beginning of the world financial crisis, accession of new Member States to the European Union, certain changes in legislation, technological breakthroughs. It is also worth noting that in some pillars, like ‘4. Health and primary education’ and ‘5. Higher education and training’ effects should only be expected to occur after certain periods of time, which makes it necessary to continue the present research.

4 Conclusions

With the present temporal and threshold analysis of the WEF’s Global Competitiveness Reports data for the EU Member States, we aim to continue and further elaborate on our analysis of the revealed relations between the twelve pillars of competitiveness. The observed positive consonances show certain changes and trends that may yield fruitful further analyses by interested economists. The presented approach for InterCriteria Decision Making also presents as a useful application of the theory of index matrices and of intuitionistic fuzzy sets.

The conclusions about how the competitiveness pillars correlate might help answer many questions about how European economies innovate, and would be useful for the EU Member States’ national policy makers, in order to better identify and strengthen the transformative forces that drive the future economic growth of their countries. Despite that we have focused on data related to EU Member States, the same approach can be equally applied to other selections of countries and time periods, and analysing the differences with the hitherto presented results will be very informative and challenging.

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