hSNS – Portuguese public hospital performance assessment using a multicriteria decision analysis framework

A network Data Envelopment Analysis to estimate nations' efficiency on the fight against SARS-CoV-2

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Organization

Motivation

- The ongoing SARS-CoV-2 pandemic is deeply impacting health systems worldwide;

- COVID-19 is characterized by relatively high admission rates for patients, particularly those requiring intensive care unit (ICU) treatment (Remuzzi & Remuzzi, 2020), and long hospital stays (Rees et al., 2020);

- This drastically diminishes the response capacity of health services to provide consistent and appropriate care for COVID and non-COVID patients;

- It is, thus, important to assess the efficiency of different countries in responding to the current crisis, identifying which health systems are presenting the best/worst performances.

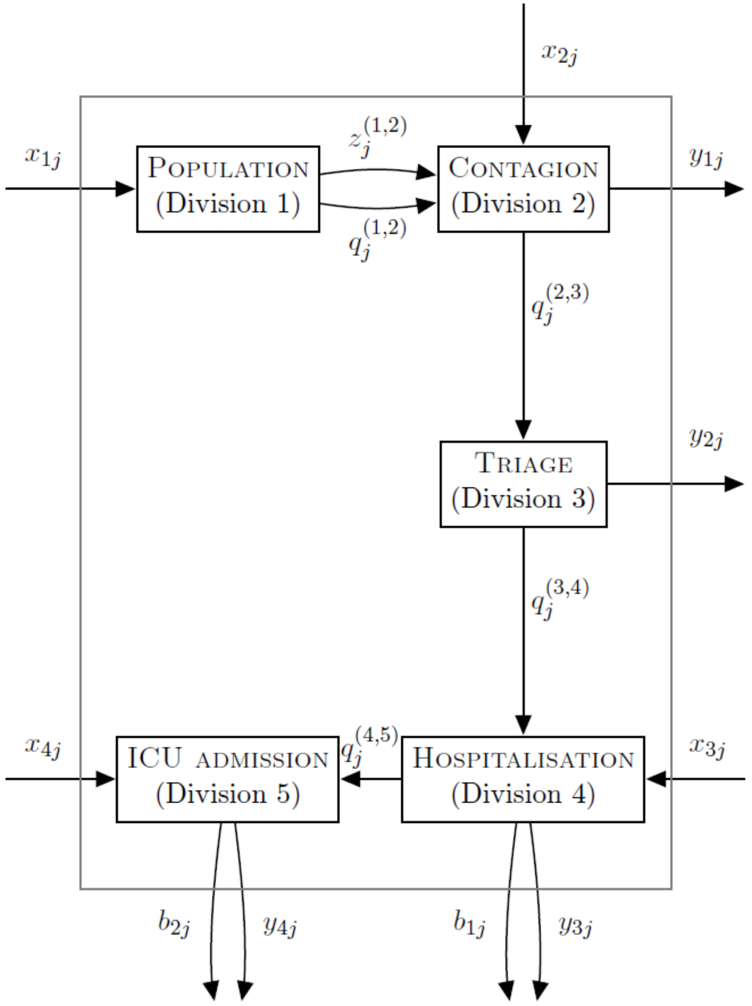
Network Data Envelopment Analysis (DEA)

- Network DEA extends conventional DEA by considering the internal structures of the entities under analysis, the *decision-making units* (DMUs), for efficiency measurement;

- The approach allows the internal components of a DMU to be assessed by considering intermediate inputs (or products), and intermediate outputs, both desirable and undesirable;

- As with DEA, network DEA models can be oriented to output-maximization, or input-minimization.

General series structure with five single-division stages



Inputs

x_{1j} – health expenditure (M€)
x_{2j} – testing equipment (€)
x_{3j} – disinfection and sterilisation (€)
x_{4j} – oxygen therapy (€)

Desirable intermediate products

$z_j^{(1,2)}$ – population that use PPE

Undesirable intermediate products

$q_j^{(1,2)}$ – pop. that does not use PPE
$q_j^{(2,3)}$ – infected pop.
$q_j^{(3,4)}$ – infected pop. in hospital
$q_j^{(4,5)}$ – hospital pop. in ICU

Desirable outputs

y_{1j} – non – infected pop.
y_{2j} – home recoveries
y_{3j} – hospital recoveries
y_{4j} – ICU recoveries

Undesirable outputs

b_{1j} – hospital deaths
b_{2j} – ICU deaths

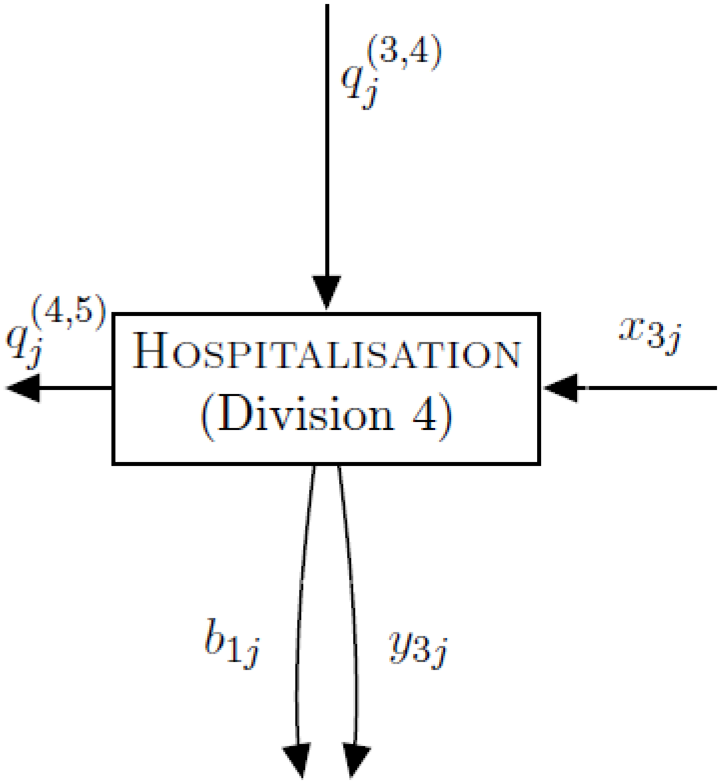
Division-wise constraints and efficiency (Example: Division 4)

Constraint

$$-w^{(4)}q_j^{(3,4)} + v_3^{(4)}x_{3j}^{(4)} - \left(-\hat{w}^{(4)}q_j^{(4,5)}\right) - u_3^{(4)}y_{3j}^{(4)} - \left(-\hat{u}_1^{(4)}b_{1j}^{(4)}\right) \geqslant 0,$$

Efficiency

$$E_j^{(4)} = \frac{w^{(4)}q_j^{(3,4)} + u_3^{(4)}y_{3j}^{(4)}}{v_3^{(4)}x_{3j}^{(4)} + \hat{w}^{(4)}q_j^{(4,5)} + \hat{u}_1^{(4)}b_{1j}^{(4)}}$$



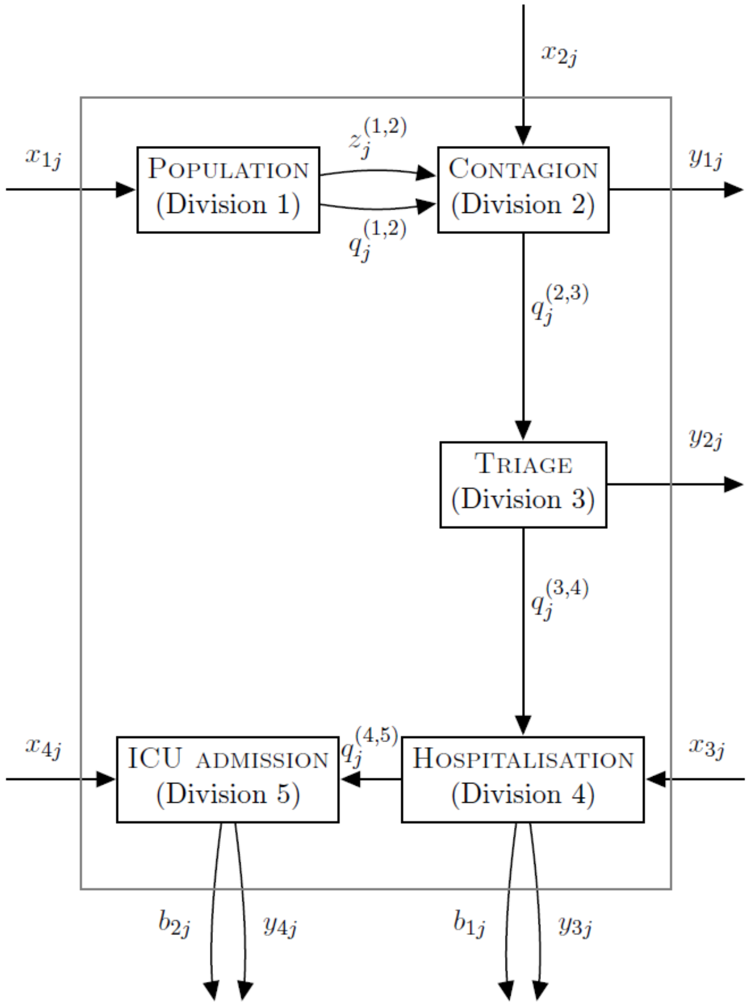
System-wise constraints and efficiency

Constraint

$$v_1^{(1)} x_{1j}^{(1)} + v_2^{(2)} x_{2j}^{(2)} + v_3^{(4)} x_{3j}^{(4)} + v_4^{(5)} x_{4j}^{(5)} -$$
$$- u_1^{(2)} y_{1j}^{(2)} - u_2^{(3)} y_{2j}^{(3)} - u_3^{(4)} y_{3j}^{(4)} - \left(-\hat{u}_1^{(4)} b_{1j}^{(4)}\right) - u_4^{(5)} y_{4j}^{(5)} - \left(-\hat{u}_2^{(5)} b_{2j}^{(5)}\right) \geqslant 0,$$

Efficiency

$$E_j = \frac{u_1^{(2)} y_{1j}^{(2)} + u_2^{(3)} y_{2j}^{(3)} + u_3^{(4)} y_{3j}^{(4)} + u_4^{(5)} y_{4j}^{(5)}}{v_1^{(1)} x_{1j}^{(1)} + v_2^{(2)} x_{2j}^{(2)} + v_3^{(4)} x_{3j}^{(4)} + v_4^{(5)} x_{4j}^{(5)} + \hat{u}_1^{(4)} b_{1j}^{(4)} + \hat{u}_2^{(5)} b_{2j}^{(5)}}.$$



Output oriented model – SOCIAL PERSPECTIVE

$$
\begin{aligned}
\text{min} \quad & v_1^{(1)} x_{1jo}^{(1)} + v_2^{(2)} x_{2jo}^{(2)} + v_3^{(4)} x_{3jo}^{(4)} + v_4^{(5)} x_{4jo}^{(5)} + c_0 \\
\text{subject to:} \quad & u_1^{(2)} y_{1jo}^{(2)} + u_2^{(3)} y_{2jo}^{(3)} + u_3^{(4)} \alpha_{3jo}^{(4,o)} q_{jo}^{(3,4)} - \hat{u}_1^{(4)} \alpha_{1jo}^{(4,o)} q_{jo}^{(3,4)} + \\
& + u_4^{(5)} \alpha_{4jo}^{(5,o)} q_{jo}^{(4,5)} - \hat{u}_2^{(5)} \alpha_{2jo}^{(5,o)} q_{jo}^{(4,5)} = 1 \\
& v_1^{(1)} x_{1j}^{(1)} + v_2^{(2)} x_{2j}^{(2)} + v_3^{(4)} x_{3j}^{(4)} + v_4^{(5)} x_{4j}^{(5)} - \\
& - u_1^{(2)} y_{1j}^{(2)} - u_2^{(3)} y_{2j}^{(3)} - u_3^{(4)} \alpha_{3j}^{(4,o)} q_j^{(3,4)} + \hat{u}_1^{(4)} \alpha_{1j}^{(4,o)} q_j^{(3,4)} - \\
& - u_4^{(5)} \alpha_{4j}^{(5,o)} q_j^{(4,5)} + \hat{u}_2^{(5)} \alpha_{2j}^{(5,o)} q_j^{(4,5)} + c_0 \geqslant 0 & j = 1, \ldots, n \\
& v_1^{(1)} x_{1j}^{(1)} - \hat{w}^{(1_z)} z_j^{(1,2)} + \hat{w}^{(1_q)} q_j^{(1,2)} + c_0 \geqslant 0, & j = 1, \ldots, n \\
& w^{(2_z)} z_j^{(1,2)} - w^{(2_q)} q_j^{(1,2)} + v_2^{(2)} x_{2j}^{(2)} + \hat{w}^{(2)} q_j^{(2,3)} - \\
& - u_1^{(2)} y_{1j}^{(2)} + c_0 \geqslant 0, & j = 1, \ldots, n \\
& - w^{(3)} q_j^{(2,3)} + \hat{w}^{(3)} q_j^{(3,4)} - u_2^{(3)} y_{2j}^{(3)} + c_0 \geqslant 0, & j = 1, \ldots, n \\
& - w^{(4)} q_j^{(3,4)} + v_3^{(4)} x_{3j}^{(4)} + \hat{w}^{(4)} q_j^{(4,5)} - u_3^{(4)} \alpha_{3j}^{(4,o)} q_j^{(3,4)} + \\
& + \hat{u}_1^{(4)} \alpha_{1j}^{(4,o)} q_j^{(3,4)} + c_0 \geqslant 0, & j = 1, \ldots, n \\
& - w^{(5)} q_j^{(4,5)} + v_4^{(5)} x_{4j}^{(5)} - u_4^{(5)} \alpha_{4j}^{(5,o)} q_j^{(4,5)} + \hat{u}_2^{(5)} \alpha_{2j}^{(5,o)} q_j^{(4,5)} + \\
& + c_0 \geqslant 0, & j = 1, \ldots, n \\
& c_0, \hat{w}^{(1_q)}, w^{(2_q)} \hat{w}^{(2)}, \hat{w}^{(3)}, w^{(3)}, \hat{w}^{(4)}, \hat{u}_1^{(4)}, w^{(4)}, \hat{u}_2^{(5)}, \\
& \text{and } w^{(5)} \text{ are free} \\
& \hat{w}^{(1_z)}, v_1^{(1)}, w^{(2_z)}, u_1^{(2)}, v_2^{(2)}, u_2^{(3)}, u_3^{(4)}, v_3^{(4)}, u_4^{(5)}, v_4^{(5)} \geqslant \varepsilon
\end{aligned}
$$

where c_0 is the intercept and $\varepsilon = 0.001$.

Input oriented model – ECONOMIC PERSPECTIVE

$$
\begin{array}{lll}
\max & u_1^{(2)} y_{1j_0}^{(2)} + u_2^{(3)} y_{2j_0}^{(3)} + u_3^{(4)} \alpha_{3j_0}^{(4,o)} q_{j_0}^{(3,4)} - \hat{u}_1^{(4)} \alpha_{1j_0}^{(4,o)} q_{j_0}^{(3,4)} + & \\
 & + u_4^{(5)} \alpha_{4j_0}^{(5,o)} q_{j_0}^{(4,5)} - \hat{u}_2^{(5)} \alpha_{2j_0}^{(5,o)} q_{j_0}^{(4,5)} + c_0 & \\
\text{subject to:} & v_1^{(1)} x_{1j_0}^{(1)} + v_2^{(2)} x_{2j_0}^{(2)} + v_3^{(4)} x_{3j_0}^{(4)} + v_4^{(5)} x_{4j_0}^{(5)} = 1 & \\
 & - v_1^{(1)} x_{1j}^{(1)} - v_2^{(2)} x_{2j}^{(2)} - v_3^{(4)} x_{3j}^{(4)} - v_4^{(5)} x_{4j}^{(5)} + & \\
 & + u_1^{(2)} y_{1j}^{(2)} + u_2^{(3)} y_{2j}^{(3)} + u_3^{(4)} \alpha_{3j}^{(4,o)} q_j^{(3,4)} - \hat{u}_1^{(4)} \alpha_{1j}^{(4,o)} q_j^{(3,4)} + & \\
 & + u_4^{(5)} \alpha_{4j}^{(5,o)} q_j^{(4,5)} - \hat{u}_2^{(5)} \alpha_{2j}^{(5,o)} q_j^{(4,5)} + c_0 \leqslant 0 & j = 1, \ldots, n \\
 & - v_1^{(1)} x_{1j}^{(1)} + \hat{w}^{(1_z)} z_j^{(1,2)} - \hat{w}^{(1_q)} q_j^{(1,2)} + c_0 \leqslant 0, & j = 1, \ldots, n \\
 & - w^{(2_z)} z_j^{(1,2)} + w^{(2_q)} q_j^{(1,2)} - v_2^{(2)} x_{2j}^{(2)} - \hat{w}^{(2)} q_j^{(2,3)} + & \\
 & + u_1^{(2)} y_{1j}^{(2)} + c_0 \leqslant 0, & j = 1, \ldots, n \\
 & w^{(3)} q_j^{(2,3)} - \hat{w}^{(3)} q_j^{(3,4)} + u_2^{(3)} y_{2j}^{(3)} + c_0 \leqslant 0, & j = 1, \ldots, n \\
 & w^{(4)} q_j^{(3,4)} - v_3^{(4)} x_{3j}^{(4)} - \hat{w}^{(4)} q_j^{(4,5)} + u_3^{(4)} \alpha_{3j}^{(4,o)} q_j^{(3,4)} - & \\
 & - \hat{u}_1^{(4)} \alpha_{1j}^{(4,o)} q_j^{(3,4)} + c_0 \leqslant 0, & j = 1, \ldots, n \\
 & w^{(5)} q_j^{(4,5)} - v_4^{(5)} x_{4j}^{(5)} + u_4^{(5)} \alpha_{4j}^{(5,o)} q_j^{(4,5)} - \hat{u}_2^{(5)} \alpha_{2j}^{(5,o)} q_j^{(4,5)} + & \\
 & + c_0 \leqslant 0, & j = 1, \ldots, n \\
 & c_0, \hat{w}^{(1_q)}, w^{(2_q)} \hat{w}^{(2)}, \hat{w}^{(3)}, w^{(3)}, \hat{w}^{(4)}, \hat{u}_1^{(4)}, w^{(4)}, \hat{u}_2^{(5)}, & \\
 & \text{and } w^{(5)} \text{ are free} & \\
 & \hat{w}^{(1_z)}, v_1^{(1)}, w^{(2_z)}, u_1^{(2)}, v_2^{(2)}, u_2^{(3)}, u_3^{(4)}, v_3^{(4)}, u_4^{(5)}, v_4^{(5)} \geqslant \varepsilon. &
\end{array}
$$

Dealing with missing data

- Some values for x_{1j}, x_{2j}, x_{3j}, x_{4j}, ${q_j}^{(3,4)}$, ${q_j}^{(4,5)}$ and y_{1j} have been estimated through linear regression;

- Values for y_{3j}, y_{4j}, b_{1j}, and b_{2j} have been rewritten as a function of the intermediate products that generate them in a given division p, weighted by a simulated value $\alpha^{(p,o)}$ (where o denotes the operational environment):

$$\begin{cases} y_{3j} = \alpha_{3j}^{(4,o)} q_j^{(3,4)}, \\ b_{1j} = \alpha_{1j}^{(4,o)} q_j^{(3,4)}, \\ y_{4j} = \alpha_{4j}^{(5,o)} q_j^{(4,5)}, \\ b_{2j} = \alpha_{2j}^{(5,o)} q_j^{(4,5)}, \end{cases}$$

where:

$$\alpha_{3j}^{(4,o)} + \alpha_{1j}^{(4,o)} + \frac{q_j^{(4,5)}}{q_j^{(3,4)}} = 1$$

$$\alpha_{4j}^{(5,o)} + \alpha_{2j}^{(5,o)} = 1$$

$\alpha_{1j}^{(4,o)} \sim U(0.12, 0.22)$ (Piroth et al., 2020)

$\alpha_{2j}^{(5,o)} \sim U(0.72, 0.82)$ (Rahim et al., 2020)

Case study – Countries

- A total of 55 countries, modelled as DMUs, have been assessed for 2020:

OECD Members (37)		
Australia	Hungary	Poland
Austria	Iceland	Portugal
Belgium	Ireland	Slovakia
Canada	Israel	Slovenia
Chile	Italy	South Korea
Colombia	Japan	Spain
Czechia	Latvia	Sweden
Denmark	Lithuania	Switzerland
Estonia	Luxembourg	Turkey
Finland	Mexico	United Kingdom
France	Netherlands	United States
Germany	New Zealand	
Greece	Norway	

OECD prospective members (6)
Argentina
Brazil
Bulgaria
Croatia
Peru
Romania

OECD key partners (4)
China
India
Indonesia
South Africa

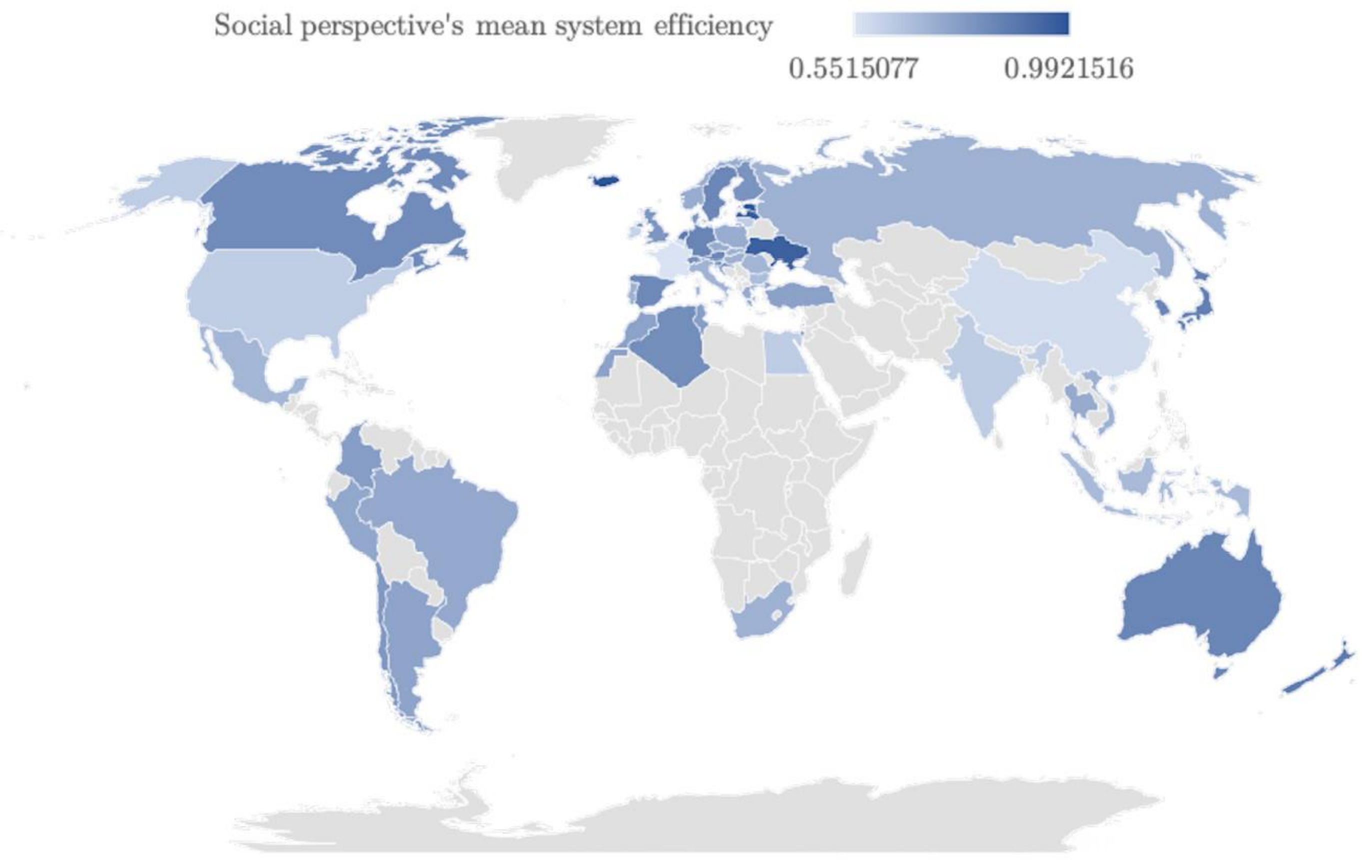
Other countries (8)
Algeria
Egypt
Morocco
Russia
Thailand
Tunisia
Ukraine
Vietnam

Case study – Descriptive statistics

Indicators	Average	Standard deviation	Minimum	Maximum
x_{1j} (M€)	123,447	415,134	1,764	3,017,112
x_{2j} (€)	2,600,849,323	4,974,551,976	11,635,269	2,9036,229,752
x_{3j} (€)	234,017,589	395,991,994	13,316,280 €	2,505,707,645
x_{4j} (€)	477,753,640	773,360,577	9,225,565	4,975,291,796
$z_j^{(1,2)}$	64,463,704	165,860,132	192,889	897,002,850
$q_j^{(1,2)}$	33,376,536	101,392,442	119,435	590,122,748
$q_j^{(2,3)}$	296,877	1,117,458	55	8,035,801
$q_j^{(3,4)}$	11,224	20,827	5	125,379
$q_j^{(4,5)}$	1,726	4,125	1	29,179
y_{1j}	96,495,080	264,351,979	335,489	1,439,236,705
y_{2j}	285,653	1,100,397	50	7,910,422

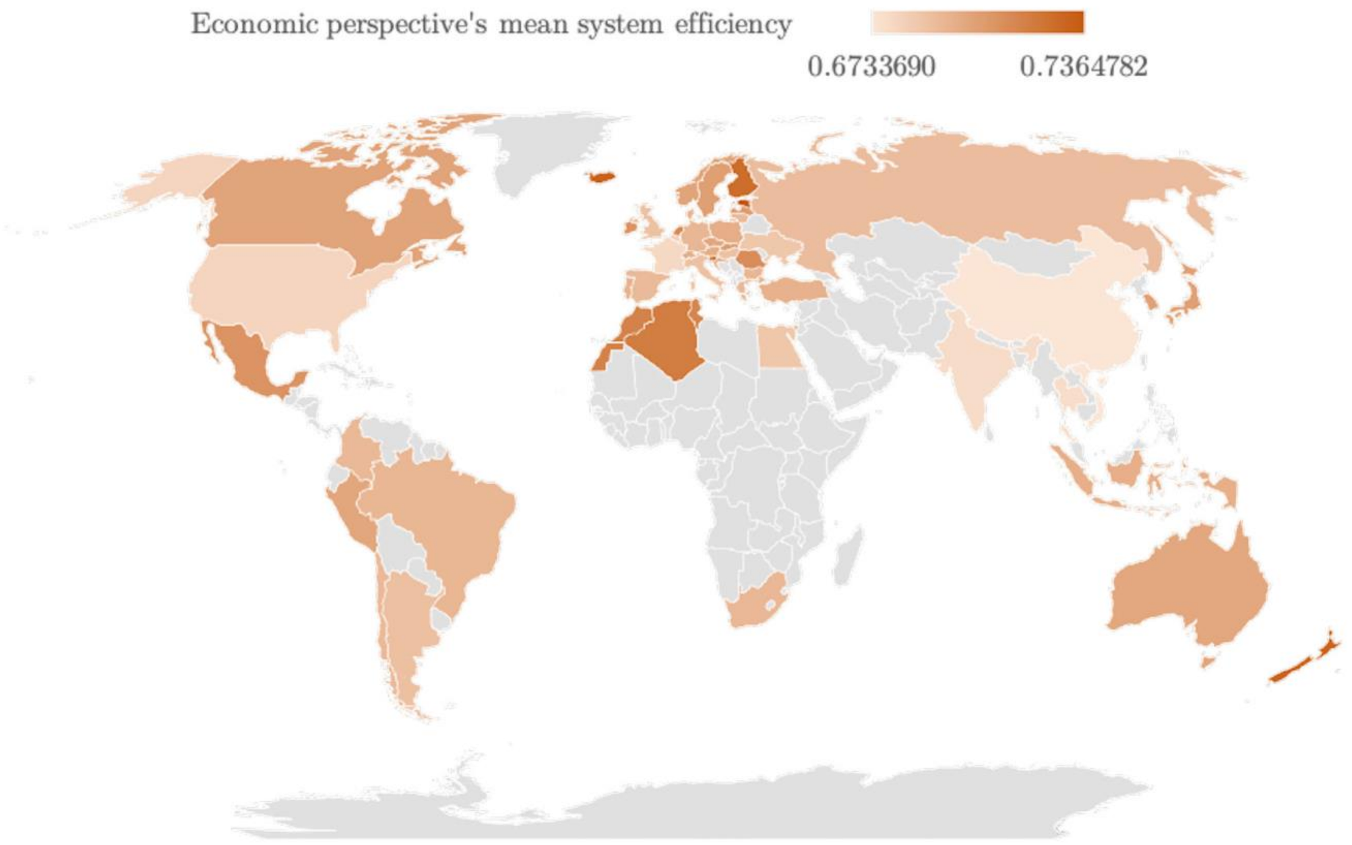
Case study – Results – SOCIAL PERSPECTIVE

Country	Division 1	Division 2	Division 3	Division 4	Division 5	System
Algeria						
Argentina						
Australia						
Austria						
Belgium						
Brazil						
Bulgaria						
Canada						
Chile						
China						
Colombia						
Croatia						
Czechia						
Denmark						
Egypt						
Estonia						
Finland						
France						
Germany						
Greece						
Hungary						
Iceland						
India						
Indonesia						
Ireland						
Israel						
Italy						
Japan						
Latvia						
Lithuania						
Luxembourg						
Mexico						
Morocco						
Netherlands						
New Zealand						
Norway						
Peru						
Poland						
Portugal						
Romania						
Russia						
Slovakia						
Slovenia						
South Africa						
South Korea						
Spain						
Sweden						
Switzerland						
Thailand						
Tunisia						
Turkey						
Ukraine						
UK						
USA						
Vietnam						
Arithmetic average	0.96702093	0.86924739	0.51160671	0.59859833	0.59438493	0.75886785
Standard deviation	0.05264748	0.04936567	0.02478319	0.04371239	0.02002393	0.10431266
Minimum	0.76053580	0.71950040	0.50000000	0.57228790	0.58255700	0.55150770
Maximum	0.99849850	0.91843560	0.64390490	0.88282970	0.70541170	0.99215160



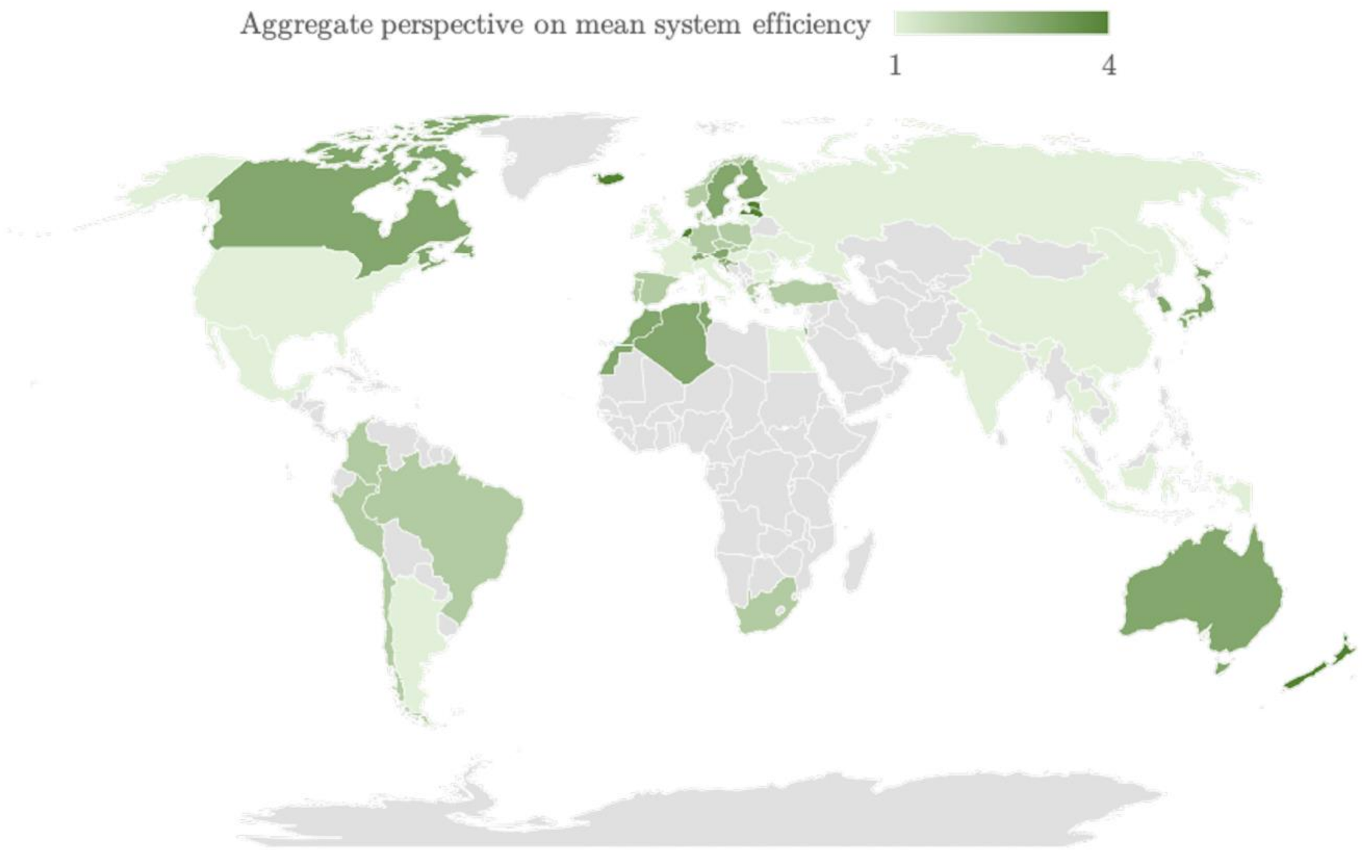
Case study – Results – ECONOMIC PERSPECTIVE

Country	Division 1	Division 2	Division 3	Division 4	Division 5	System
Algeria						
Argentina						
Australia						
Austria						
Belgium						
Brazil						
Bulgaria						
Canada						
Chile						
China						
Colombia						
Croatia						
Czechia						
Denmark						
Egypt						
Estonia						
Finland						
France						
Germany						
Greece						
Hungary						
Iceland						
India						
Indonesia						
Ireland						
Israel						
Italy						
Japan						
Latvia						
Lithuania						
Luxembourg						
Mexico						
Morocco						
Netherlands						
New Zealand						
Norway						
Peru						
Poland						
Portugal						
Romania						
Russia						
Slovakia						
Slovenia						
South Africa						
South Korea						
Spain						
Sweden						
Switzerland						
Thailand						
Tunisia						
Turkey						
Ukraine						
United Kingdom						
United States						
Vietnam						
Arithmetic average	0.67436468	0.74667362	0.56743796	0.67141524	0.77727810	0.70009390
Standard deviation	0.02150417	0.01909692	0.04655813	0.02087512	0.02790822	0.01507299
Minimum	0.64594710	0.66674270	0.53682060	0.63396660	0.64800770	0.67336900
Maximum	0.81813530	0.78943140	0.80564420	0.75904250	0.83860060	0.73647820



Case study – Results – AGGREGATE PERSPECTIVE

Social perspective \ Economic perspective	Q1	Q2	Q3	Q4
Q1	4	3	2	1
Q2	3	3	2	1
Q3	2	2	2	1
Q4	1	1	1	1



Conclusions

- None of the DMUs is systematically efficient on average in any of the considered perspectives – SOCIAL and ECONOMIC;

- Estonia, Iceland, Latvia, Luxembourg, the Netherlands, and New Zealand (≈10% of the sample) present high mean system efficiency scores in the AGGREGATE PERSPECTIVE (Q1 level);

- A total of 20 countries (≈36% of the sample) present low mean system efficiency scores in the AGGREGATE PERSPECTIVE (Q4 level);

Conclusions (cont.)

- Australia, Austria, Estonia, Germany, Iceland, Japan, Latvia, Luxembourg, the Netherlands, New Zealand, South Korea, Spain, Sweden, and Ukraine (≈25% of the sample) present high mean system efficiency scores in the SOCIAL PERSPECTIVE (Q1 level);

- Another 14 countries (≈25% of the sample) present low mean system efficiency scores in the SOCIAL PERSPECTIVE (Q4 level);

Conclusions (cont.)

- Algeria, Estonia, Finland, Iceland, Ireland, Latvia, Luxembourg, Mexico, Morocco, the Netherlands, New Zealand, Romania, Slovenia, and Tunisia (≈25% of the sample) present high mean system efficiency scores in the ECONOMIC PERSPECTIVE (Q1 level);

- Another 14 countries (≈25% of the sample) present low mean system efficiency scores in the ECONOMIC PERSPECTIVE (Q4 level).

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Remuzzi, A., & Remuzzi, G. (2020). COVID-19 and Italy: what next? *The Lancet, 395*, 1225-1228. doi:10.1016/S0140-6736(20)30627-9

Thank you!

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