Ranking the effectiveness of worldwide COVID-19 government interventions

Dr Sara Romano-Bertrand MCU-PH

Equipe PHySE, UMR Hydrosciences, Université Montpellier

Département d'Hygiène Hospitalière, CHU Montpellier

@hsm_physe *@SRomanoBertrand*

MUSE

MONTPELLIER UNIVERSITÉ D'EXCELLENCE

Pathogènes Environnements Hydriques Santé

HSM

CHU Département D'Hygiène Hospitalière

Nom : Sara, ROMANO-BERTRAND, Montpellier

☑ Je n'ai pas de lien d'intérêt potentiel à déclarer

nature human behaviour

| VOL 4 | DECEMBER 2020 | 1303–1312 | www.nature.com/nathumbehav

ARTICLES

https://doi.org/10.1038/s41562-020-01009-0

Check for updates

Ranking the effectiveness of worldwide COVID-19 government interventions

Nils Haug[1,2,7], Lukas Geyrhofer[2,7], Alessandro Londei[3], Elma Dervic[1,2], Amélie Desvars-Larrive[2,4], Vittorio Loreto[2,3,5], Beate Pinior[2,4], Stefan Thurner[1,2,6] and Peter Klimek[1,2] ✉

1. Medical University of Vienna, Section for Science of Complex Systems, CeMSIIS, Vienna, Austria.
2. Complexity Science Hub Vienna, Vienna, Austria.
3. Sony Computer Science Laboratories, Paris, France.
4. Unit of Veterinary Public Health and Epidemiology, Institute of Food Safety, Food Technology and Veterinary Public Health, University of Veterinary Medicine, Vienna, Austria.
5. Physics Department, Sapienza University of Rome, Rome, Italy.
6. Santa Fe Institute, Santa Fe, NM, USA.

The context of the COVID-19 Pandemic

New emergent pandemic, with rapid spread of SARS-CoV-2 first in China, then in the entire world
⇒ reactive measures implemented by governments

Before vaccines, and while no antiviral medication is available to cure COVID-19 patients,
non-pharmaceutical interventions (NPIs) = sole measures to constraint SARS-CoV-2 spread.

Large range of different NPIs adopted worldwide
some being intrusive or highly restrictive

Lack of scientific evidence of effectiveness of some NPIs :
When applied individually or in combination
According to the degree of population compliance

Evolutive epidemiology urging rapid decisions.

⇒ **Bundles of measures** usually implemented, making effectiveness difficult to assess

Objective

Quantifying and ranking the effectiveness of non-pharmaceutical interventions
to mitigate SARS-CoV-2 spread and to prepare future response plans.

$\Rightarrow$ Monitoring, documenting and assessing government strategies to constraint the pandemic evolution

$\Rightarrow$ Identifying a consensus set of NPIs that lead to significant reduction in R_t

$\Rightarrow$ **Help in decision in the final goal of better mitigating the pandemic**

Methodology: NPIs data

6,068 NPIs implemented in 79 territories worldwide

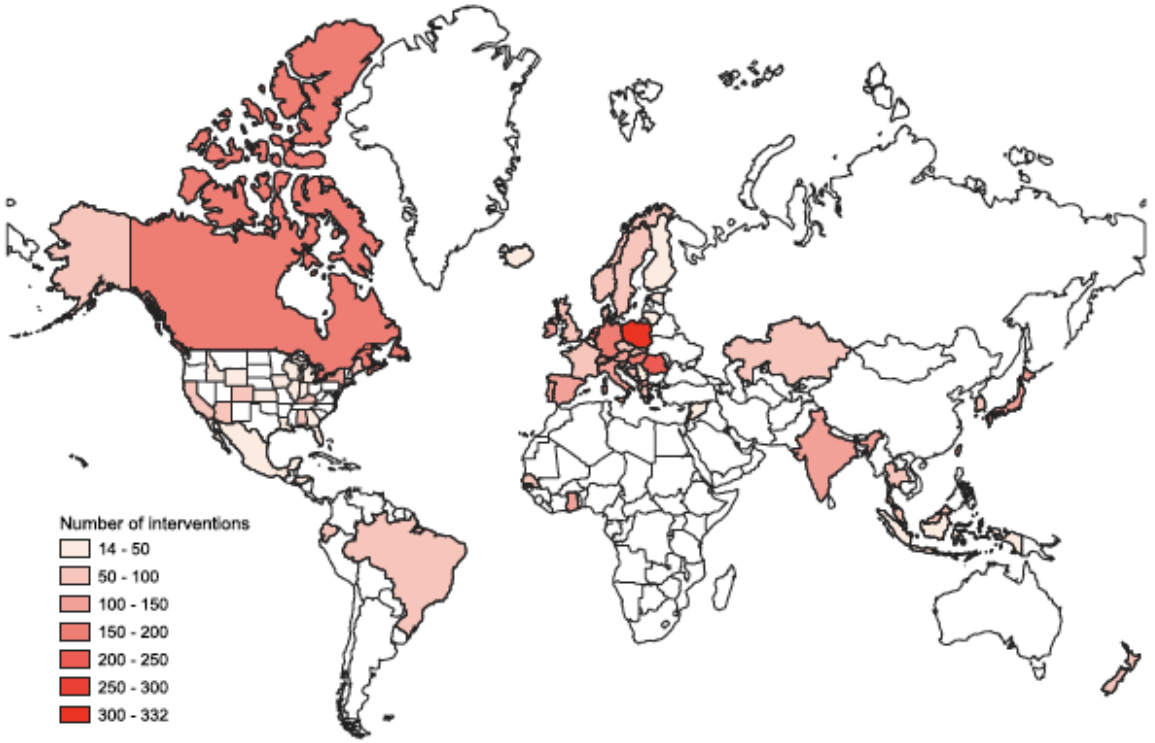


Fig. 1 Geographical coverage of the CCCSL and total number of recorded NPIs that were implemented in each country to control the spread of COVID-19. As of date of submission, the dataset includes 56 countries and dates of NPI implementation range from 31/12/2019 to 15/07/2020.

Complexity Science Hub COVID-19 Control Strategies List (CCCSL)[1] : dataset providing a hierarchic taxonomy of 6,068 NPIs coded in four levels (L1 to L4):

- eight **broad themes (L1)**
- 63 **categories (L2)** of individual NPIs
- >500 **sub-categories (L3)**
- >2,000 **codes (L4).**

Theme (L1)	Number of records	Frequency
Case identification, contact tracing and related measures	540	0.09
Environmental measures	62	0.01
Healthcare and public health capacity	808	0.13
Resource allocation	958	0.16
Returning to normal life	316	0.05
Risk communication	1,074	0.18
Social distancing	1,673	0.28
Travel restriction	615	0.10

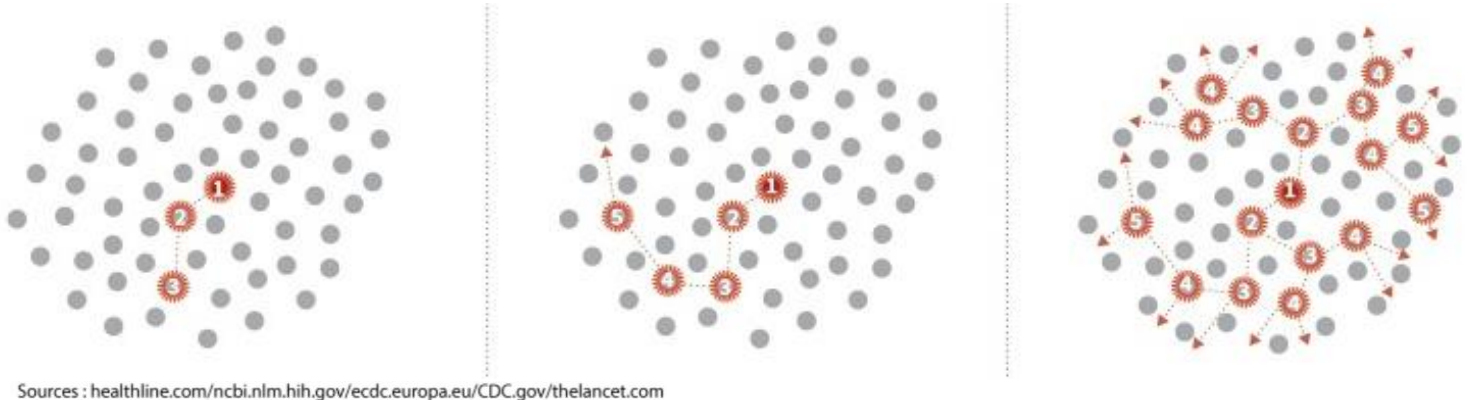
Table 1. Summary of the government interventions recorded in the CCCSL at level 1 (themes) of the coding scheme. As of date of submission, the dataset includes 56 countries and dates of NPI implementation range from 31/12/2019 to 15/07/2020.

(1) Desvars-Larrive 2020, https://github.com/amel-github/CCCSL-Codes

Methodology: COVID-19 case data

NPIs impact was quantified on the effective reproduction number R_t of COVID-19

To estimate R_t and growth rates of the number of COVID-19 cases: use of time series of the number of confirmed COVID-19 cases in the 79 territories considered *(R package EpiEstim[2])*
and a sliding time window of 7 days to estimate the time series of R_t.
uncertain serial interval following a probability distribution with a mean of 4.46 days and a standard deviation of 2.63 days was applied [3]



Sources : healthline.com/ncbi.nlm.hih.gov/ecdc.europa.eu/CDC.gov/thelancet.com

To control for weekly fluctuations: time series were smoothed by computing the rolling average
using a Gaussian window with a standard deviation of 2 days, truncated at a maximum window size of 15 days.

(2) Cori 2013. A new framework and software to estimate time-varying reproduction numbers during epidemics. Am. J. Epidemiol. 178, 1505–1512.
(3). Valka 2020. Estimation and interactive visualization of the time-varying reproduction number Rt and the time-delay from infection to estimation. Preprint at medRxiv
https://doi.org/10.1101/2020.09.19.20197970

Methodology: Regression techniques

Four different statistical approaches were applied to quantify the impact of a NPI (*M*) on the reduction in R_t

(1) Case-control analysis (CC):
considers each single category (L2) or subcategory (L3) separately

evaluates in a matched comparison, the difference in R_t (ΔR_t) between all countries that implemented *M* (cases) and those that did not (controls).

The comparison was made via a linear regression model adjusting for:
- epidemic age (days after the country has reached 30 confirmed cases),
- the value of R_t before *M* takes effect,
- total population and population density,
- the total number of NPIs implemented
- the number of NPIs implemented in the same category as *M*.

Investigating
- the **time delay between implementation of *M* and the observation of ΔR_t,**
and
- additional **country-based covariates** that quantify other dimensions of governance, and human and economic development

Methodology: Regression techniques

(2) Step function in Lasso regression (Lasso)

without intervention, R_t is constant
and deviation from this constant results from a delayed onset (by τ days) of the NPI (*M*).

Lasso regression approach, combined with a meta parameter search, was used to select a reduced set of NPIs that best describe the observed ΔR_t.

Estimates for the **changes in ΔR_t attributable to *M*** are obtained from country-wise cross-validation.

τ = time **delay between adoption and onset** of the effect of a given NPI.

Methodology: Regression techniques

(2) Step function in Lasso regression (Lasso)

without intervention, R_t is constant
and deviation from this constant results from a delayed onset (by τ days) of the NPI (*M*).

Lasso regression approach, combined with a meta parameter search, was used to select a reduced set of NPIs that best describe the observed ΔR_t.

Estimates for the **changes in ΔR_t attributable to *M*** are obtained from country-wise cross-validation.

τ = time **delay between adoption and onset** of the effect of a given NPI.

The importance of a NPI is defined as the **decline in predictive performance of the RF on unseen data** if the data concerning that NPI are replaced by noise (also called permutation importance).

3) Random Forests regression (RF)

the NPIs implemented in a country are used as predictors for R_t and time-shifted (τ) days into the future.

Similar to the Lasso regression, without changes in interventions, the value of R_t in a territory remains constant. But, conversely to the two previous methods, RF represents a nonlinear model, meaning that the effects of individual NPIs on R_t do not need to add up linearly.

Methodology: Regression techniques

(4) Transformer modelling (TF)[4]

suitable for dynamic discrete element processes such as textual sequences, due to their ability to recall past events

$\Rightarrow$ the transformer architecture was extended to approach the continuous case of epidemic data, by removing the probabilistic output layer with a linear combination of transformer output, whose input is identical to that for RF regression, along with the values of R_t.

TF was used as a **predictive model** to quantify the impact of measure M on R_t.
In order to assess ΔR_t, TF compared simulations without any measure (reference) to those where one measure is presented at a time.

(4) Vaswani 2017. in Advances in Neural Information Processing Systems 30 (eds Guyon, I. et al.) 5998–6008 (Curran Associates)

Methodology: Regression techniques

(4) Transformer modelling (TF)[4]

suitable for dynamic discrete element processes such as textual sequences, due to their ability to recall past events

$\Rightarrow$ the transformer architecture was extended to approach the continuous case of epidemic data, by removing the probabilistic output layer with a linear combination of transformer output, whose input is identical to that for RF regression, along with the values of R_t.

TF was used as a **predictive model** to quantify the impact of measure M on R_t.
In order to assess ΔR_t, TF compared simulations without any measure (reference) to those where one measure is presented at a time.

NPIs were ranked in descending order according to their impact, for each methods.
To compare rankings, the authors counted how many of the consensus NPIs are classified as belonging to the top x ranked measures in all methods, and test the null hypothesis that this overlap has been obtained from completely independent rankings.

(4) Vaswani 2017. in Advances in Neural Information Processing Systems 30 (eds Guyon, I. et al.) 5998–6008 (Curran Associates)

Methodology: country-level approach

Co-implementation network
to assess a statistical tendency that a country implementing NPI *i* also implements NPI *j* later in time.

The network illustrates the **NPI implementation sequence** and steps within this sequence, that contribute most to a reduction in R_t.

Entropic country-level approach
to quantify the NPI effect according to socio-economic conditions and unique temporal sequence of NPIs adopted for a given territory.

This approach allowed to compare countries that have implemented different numbers of NPIs, and considered the normalized rankings where the ranking position is divided by the number of elements in the ranking list (*i.e.*, the number of NPIs taken in a specific country).

Investigating **country-specific control strategies** along with the impact of selected country-specific metrics.

Assessing the **heterogeneity of the effectiveness** of individuals NPIs in different territories.

Results: Congruence between the 4 methods for L1 Themes

Table: Comparison of effectiveness rankings on the L1 themes for the case-control analysis (CC), LASSO regression (LASSO), random forest regression (RF), and transformer analysis (TF).

L1 themes	CC	LASSO	RF	TF
Social distancing	**1**	**1**	**1**	**1**
Travel restriction	**2**	**2**	**2**	**2**
Healthcare and public health capacity	5	4	4	**3**
Risk communication	6	**3**	**3**	5
Resource allocation	4	6	5	4
Case identification, contact tracing and related measures	**3**	5	6	6
Environmental measures	7	7	7	7

Results: Congruence between the 4 methods for L1 Themes

Table: Comparison of effectiveness rankings on the L1 themes for the case-control analysis (CC), LASSO regression (LASSO), random forest regression (RF), and transformer analysis (TF).

L1 themes	CC	LASSO	RF	TF
Social distancing	**1**	**1**	**1**	**1**
Travel restriction	**2**	**2**	**2**	**2**
Healthcare and public health capacity	5	4	4	**3**
Risk communication	6	**3**	**3**	5
Resource allocation	4	6	5	4
Case identification, contact tracing and related measures	**3**	5	6	6
Environmental measures	7	7	7	7

NPIs regarding social distancing and travel restriction are the most effective in reducing R_t while environmental measures are the less one

Results: Congruence between the 4 methods for L1 Themes

Table: Comparison of effectiveness rankings on the L1 themes for the case-control analysis (CC), LASSO regression (LASSO), random forest regression (RF), and transformer analysis (TF).

L1 themes	CC	LASSO	RF	TF
Social distancing	**1**	**1**	**1**	**1**
Travel restriction	**2**	**2**	**2**	**2**
Healthcare and public health capacity	5	4	4	**3**
Risk communication	6	**3**	**3**	5
Resource allocation	4	6	5	4
Case identification, contact tracing and related measures	**3**	5	6	6
Environmental measures	7	7	7	7

NPIs regarding social distancing and travel restriction are the most effective in reducing R_t while environmental measures are the less one

$\Rightarrow$ allowed to identify a **consensus set of NPIs that lead to a significant reduction in R_t**.

Results: Effectiveness of 46 NPIs (L2) implemented more than 5 times

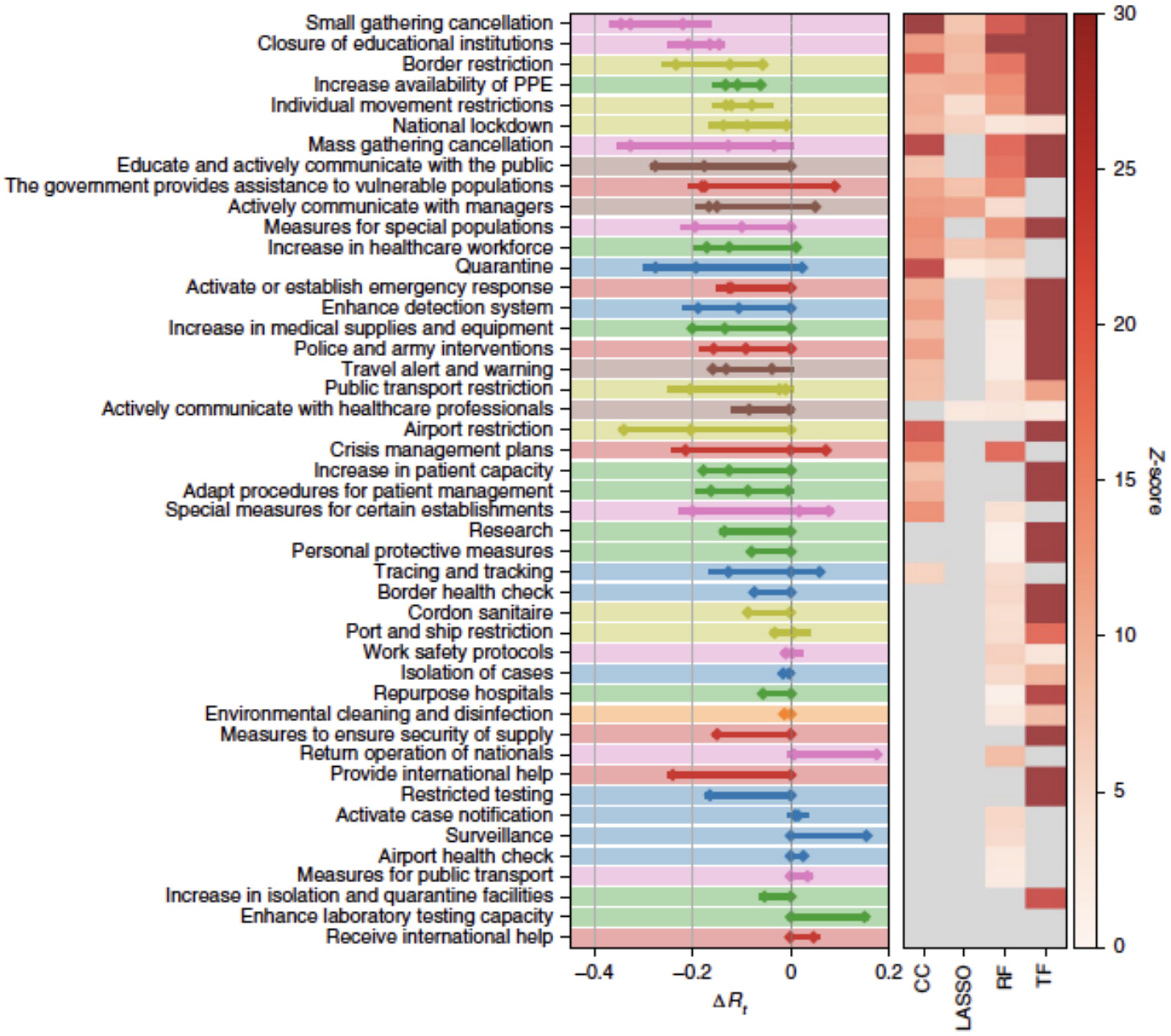


Fig. 1 | Change in R_t (ΔR_t) for 46 NPIs at L2, as quantified by CC analysis, LASSO and TF regression.

NPIs are ranked according to the number of methods agreeing on their impacts, from top (significant in all methods) to bottom (ineffective in all analyses).

The left-hand panel shows the combined 95% confidence intervals of ΔR_t for the most effective interventions across all included territories.

The heatmap shows the corresponding Z-scores of measure effectiveness as determined by the four different methods.

Grey indicates no significantly positive effect.

Results: Effectiveness of 46 NPIs (L2) implemented more than 5 times

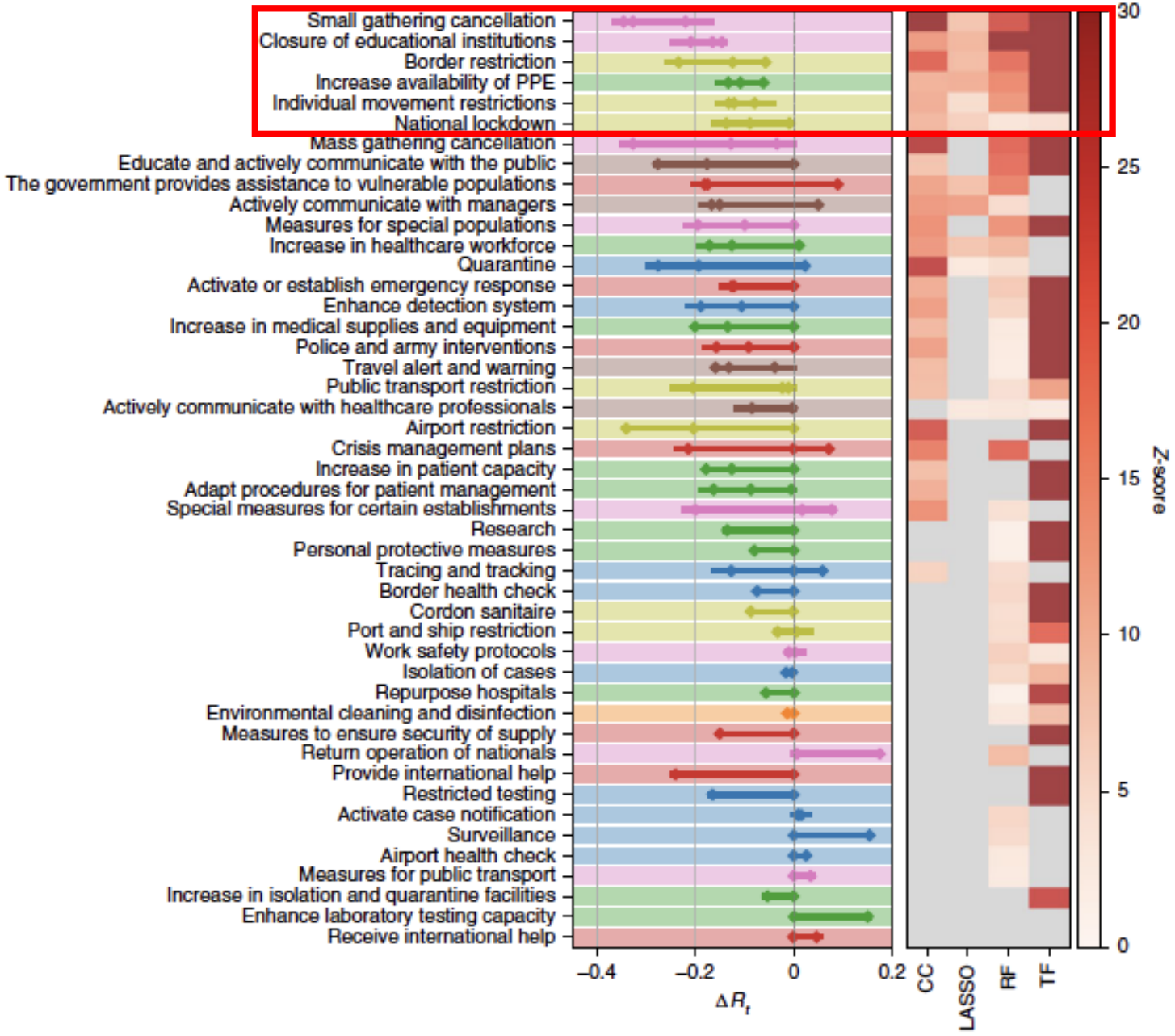


Fig. 1 | Change in R_t (ΔR_t) for 46 NPIs at L2, as quantified by CC analysis, LASSO and TF regression.

NPIs are ranked according to the number of methods agreeing on their impacts, from top (significant in all methods) to bottom (ineffective in all analyses).

The left-hand panel shows the combined 95% confidence intervals of ΔR_t for the most effective interventions across all included territories.

The heatmap shows the corresponding Z-scores of measure effectiveness as determined by the four different methods.

Grey indicates no significantly positive effect.

Six consensus NPI categories (L2) showed significant impact on R_t in all 4 methods

Results: Effectiveness of 46 NPIs (L2) implemented more than 5 times

Table 1 | Comparison of effectiveness rankings on L2

L2 category	Score (%)	Consensus	ΔR_t^{CC}	ΔR_t^{LASSO}	Importance (RF)	ΔR_t^{TF}
Small gathering cancellation	83	4	-0.35 (2)	-0.22 (5)	0.020 (2)	-0.327 (3)
Closure of educational institutions	73	4	-0.16 (2)	-0.21 (4)	0.028 (2)	-0.146 (2)
Border restriction	56	4	-0.23 (2)	-0.12 (2)	0.017 (2)	-0.057 (2)
Increased availability of PPE	51	4	-0.11 (2)	-0.13 (2)	0.012 (1)	-0.062 (2)
Individual movement restrictions	42	4	-0.13 (2)	-0.08 (3)	0.017 (2)	-0.121 (2)
National lockdown	25	4	-0.14 (3)	-0.09 (2)	0.0020 (9)	-0.008 (3)
Mass gathering cancellation	53	3	-0.33 (2)	0	0.012 (1)	-0.127 (2)
Educate and actively communicate with the public	48	3	-0.18 (4)	0	0.018 (2)	-0.276 (2)
The government provides assistance to vulnerable populations	41	3	-0.17 (3)	-0.18 (4)	0.009 (1)	0.090 (3)
Actively communicate with managers	40	3	-0.15 (2)	-0.20 (4)	0.004 (2)	-0.050 (2)
Measures for special populations	37	3	-0.19 (2)	0	0.008 (1)	-0.100 (2)
Increase healthcare workforce	35	3	-0.17 (20)	-0.13 (3)	0.030 (8)	0.011 (2)
Quarantine	30	3	-0.28 (2)	-0.2 (1)	0.0023 (9)	0.023 (2)
Activate or establish emergency response	29	3	-0.13 (2)	0	0.0037 (9)	-0.121 (2)
Enhance detection system	25	3	-0.19 (3)	0	0.0032 (9)	-0.106 (2)
Increase in medical supplies and equipment	25	3	-0.13 (3)	-0.004 (3)	0.003 (2)	-0.200 (3)
Police and army interventions	23	3	-0.16 (2)	0	0.003 (2)	-0.091 (2)
Travel alert and warning	20	3	-0.13 (3)	0.0 (1)	0.002 (1)	-0.159 (3)
Public transport restriction	13	3	00.20 (4)	-0.01 (7)	0.004 (1)	-0.023 (3)
Actively communicate with healthcare professionals	11	3	0	-0.08 (4)	0.003 (1)	-0.003 (2)

Out of the 46 NPI categories, all four methods show significant results for six NPIs (consensus 4) while three methods agree on 14 further NPIs (consensus 3). We report the average normalized score, the observed reduction in R_t for the various methods and NPI importance for RF. Numbers in parentheses denote half of the amount by which the last digit of the corresponding number outside the parentheses fluctuates within the 95% confidence interval.

For each NPI category, a normalized score was obtained by recalling the result within each method, to range between 0-100% of effectiveness.

Results: Effectiveness of 46 NPIs (L2) implemented more than 5 times

Table 1 | Comparison of effectiveness rankings on L2

L2 category	Score (%)	Consensus	ΔR_t^{CC}	ΔR_t^{LASSO}	Importance (RF)	ΔR_t^{TF}
Small gathering cancellation	83	4	-0.35 (2)	-0.22 (5)	0.020 (2)	-0.327 (3)
Closure of educational institutions	73	4	-0.16 (2)	-0.21 (4)	0.028 (2)	-0.146 (2)
Border restriction	56	4	-0.23 (2)	-0.12 (2)	0.017 (2)	-0.057 (2)
Increased availability of PPE	51	4	-0.11 (2)	-0.13 (2)	0.012 (1)	-0.062 (2)
Individual movement restrictions	42	4	-0.13 (2)	-0.08 (3)	0.017 (2)	-0.121 (2)
National lockdown	25	4	-0.14 (3)	-0.09 (2)	0.0020 (9)	-0.008 (3)
Mass gathering cancellation	53	3	-0.33 (2)	0	0.012 (1)	-0.127 (2)
Educate and actively communicate with the public	48	3	-0.18 (4)	0	0.018 (2)	-0.276 (2)
The government provides assistance to vulnerable populations	41	3	-0.17 (3)	-0.18 (4)	0.009 (1)	0.090 (3)
Actively communicate with managers	40	3	-0.15 (2)	-0.20 (4)	0.004 (2)	-0.050 (2)
Measures for special populations	37	3	-0.19 (2)	0	0.008 (1)	-0.100 (2)
Increase healthcare workforce	35	3	-0.17 (20)	-0.13 (3)	0.030 (8)	0.011 (2)
Quarantine	30	3	-0.28 (2)	-0.2 (1)	0.0023 (9)	0.023 (2)
Activate or establish emergency response	29	3	-0.13 (2)	0	0.0037 (9)	-0.121 (2)
Enhance detection system	25	3	-0.19 (3)	0	0.0032 (9)	-0.106 (2)
Increase in medical supplies and equipment	25	3	-0.13 (3)	-0.004 (3)	0.003 (2)	-0.200 (3)
Police and army interventions	23	3	-0.16 (2)	0	0.003 (2)	-0.091 (2)
Travel alert and warning	20	3	-0.13 (3)	0.0 (1)	0.002 (1)	-0.159 (3)
Public transport restriction	13	3	00.20 (4)	-0.01 (7)	0.004 (1)	-0.023 (3)
Actively communicate with healthcare professionals	11	3	0	-0.08 (4)	0.003 (1)	-0.003 (2)

Out of the 46 NPI categories, all four methods show significant results for six NPIs (consensus 4) while three methods agree on 14 further NPIs (consensus 3). We report the average normalized score, the observed reduction in R_t for the various methods and NPI importance for RF. Numbers in parentheses denote half of the amount by which the last digit of the corresponding number outside the parentheses fluctuates within the 95% confidence interval.

For each NPI category, a normalized score was obtained by recalling the result within each method, to range between 0-100% of effectiveness.

The six previous full-consensus NPI categories were retrieved.

Results: Effectiveness of 46 NPIs (L2) implemented more than 5 times

Table 1 | Comparison of effectiveness rankings on L2

L2 category	Score (%)	Consensus	ΔR_t^{CC}	ΔR_t^{LASSO}	Importance (RF)	ΔR_t^{TF}
Small gathering cancellation	83	4	-0.35 (2)	-0.22 (5)	0.020 (2)	-0.327 (3)
Closure of educational institutions	73	4	-0.16 (2)	-0.21 (4)	0.028 (2)	-0.146 (2)
Border restriction	56	4	-0.23 (2)	-0.12 (2)	0.017 (2)	-0.057 (2)
Increased availability of PPE	51	4	-0.11 (2)	-0.13 (2)	0.012 (1)	-0.062 (2)
Individual movement restrictions	42	4	-0.13 (2)	-0.08 (3)	0.017 (2)	-0.121 (2)
National lockdown	25	4	-0.14 (3)	-0.09 (2)	0.0020 (9)	-0.008 (3)
Mass gathering cancellation	53	3	-0.33 (2)	0	0.012 (1)	-0.127 (2)
Educate and actively communicate with the public	48	3	-0.18 (4)	0	0.018 (2)	-0.276 (2)
The government provides assistance to vulnerable populations	41	3	-0.17 (3)	-0.18 (4)	0.009 (1)	0.090 (3)
Actively communicate with managers	40	3	-0.15 (2)	-0.20 (4)	0.004 (2)	-0.050 (2)
Measures for special populations	37	3	-0.19 (2)	0	0.008 (1)	-0.100 (2)
Increase healthcare workforce	35	3	-0.17 (20)	-0.13 (3)	0.030 (8)	0.011 (2)
Quarantine	30	3	-0.28 (2)	-0.2 (1)	0.0023 (9)	0.023 (2)
Activate or establish emergency response	29	3	-0.13 (2)	0	0.0037 (9)	-0.121 (2)
Enhance detection system	25	3	-0.19 (3)	0	0.0032 (9)	-0.106 (2)
Increase in medical supplies and equipment	25	3	-0.13 (3)	-0.004 (3)	0.003 (2)	-0.200 (3)
Police and army interventions	23	3	-0.16 (2)	0	0.003 (2)	-0.091 (2)
Travel alert and warning	20	3	-0.13 (3)	0.0 (1)	0.002 (1)	-0.159 (3)
Public transport restriction	13	3	00.20 (4)	-0.01 (7)	0.004 (1)	-0.023 (3)
Actively communicate with healthcare professionals	11	3	0	-0.08 (4)	0.003 (1)	-0.003 (2)

Out of the 46 NPI categories, all four methods show significant results for six NPIs (consensus 4) while three methods agree on 14 further NPIs (consensus 3). We report the average normalized score, the observed reduction in R_t for the various methods and NPI importance for RF. Numbers in parentheses denote half of the amount by which the last digit of the corresponding number outside the parentheses fluctuates within the 95% confidence interval.

For each NPI category, a normalized score was obtained by recalling the result within each method, to range between 0-100% of effectiveness.

The six previous full-consensus NPI categories were retrieved.

14 additional NPI categories (L2) consensually in 3 methods

Results: NPIs effectiveness in co-implementation network

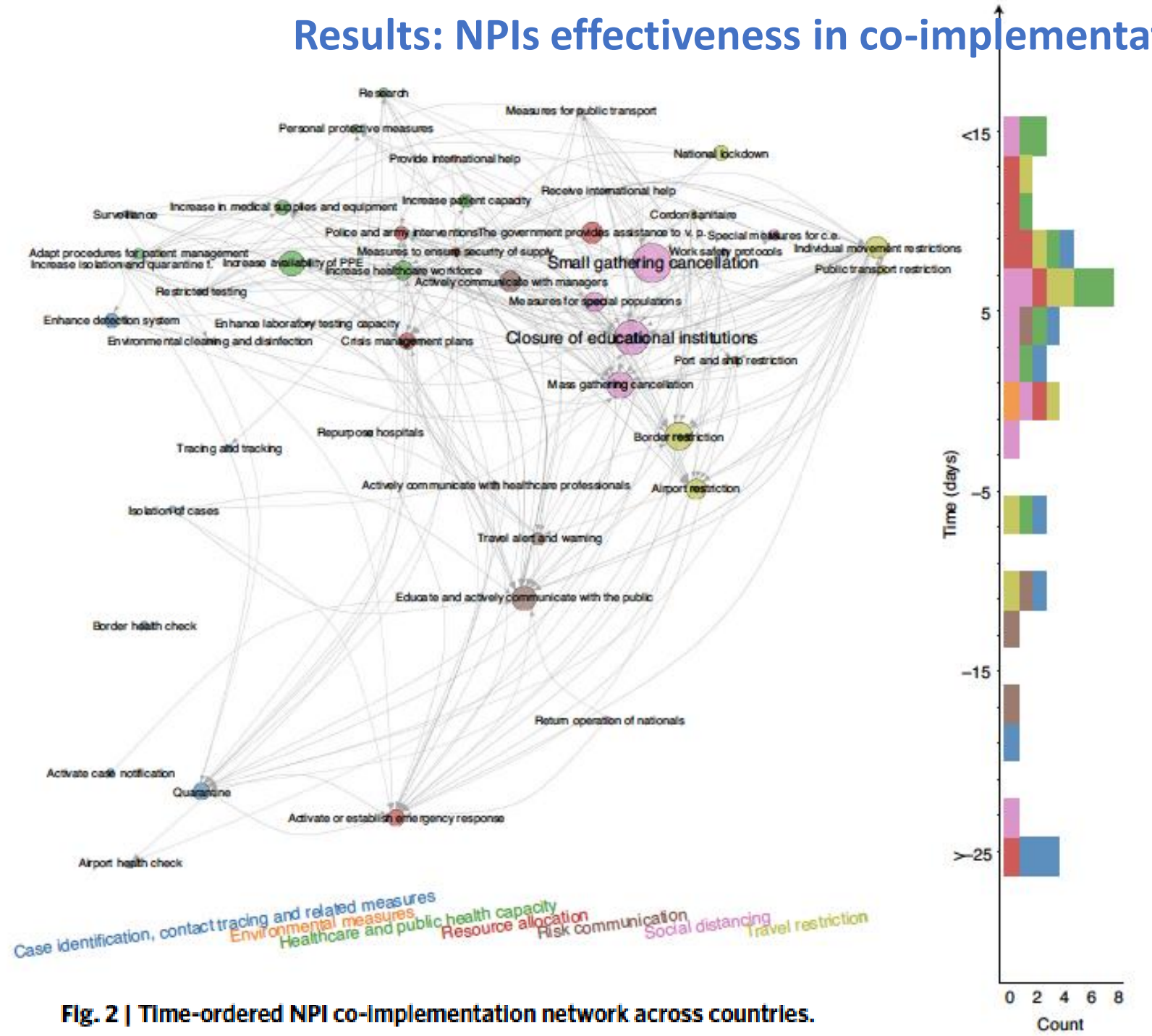


Fig. 2 | Time-ordered NPI co-implementation network across countries.

Nodes correspond to categories (L2)
Size proportional to average effectiveness of intervention
positioned vertically according to their average time of implementation

Arrows from nodes *i* to *j* indicate that countries which have already implemented intervention *i* tend to implement intervention *j* later in time.

Results: NPIs effectiveness in co-implementation network

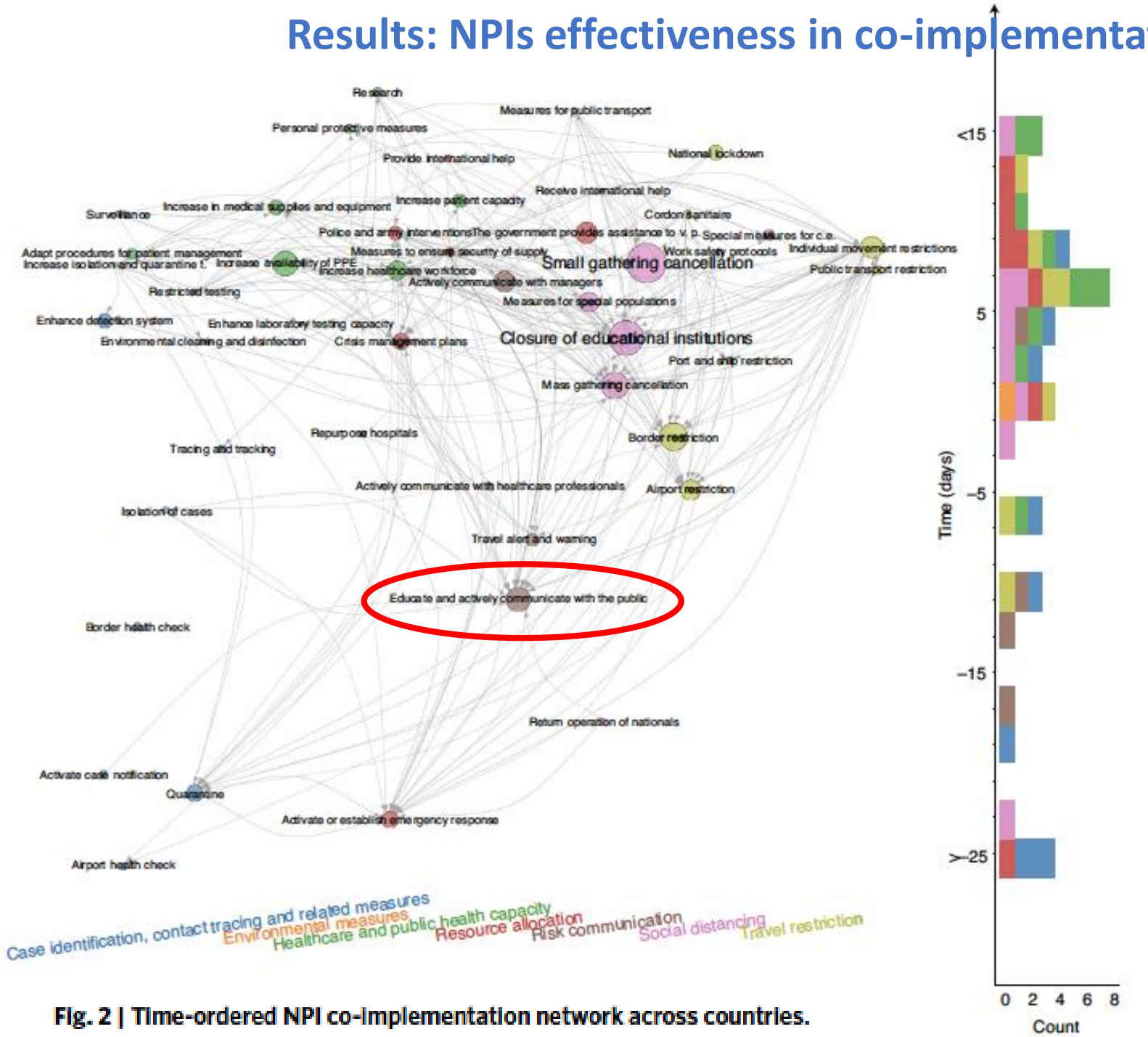


Fig. 2 | Time-ordered NPI co-implementation network across countries.

Nodes correspond to categories (L2)
Size proportional to average effectiveness of intervention
positioned vertically according to their average time of implementation

Arrows from nodes *i* to *j* indicate that countries which have already implemented intervention *i* tend to implement intervention *j* later in time.

Education and active communication with the public is one of the most effective 'early measures'.

Results: NPIs effectiveness in co-implementation network

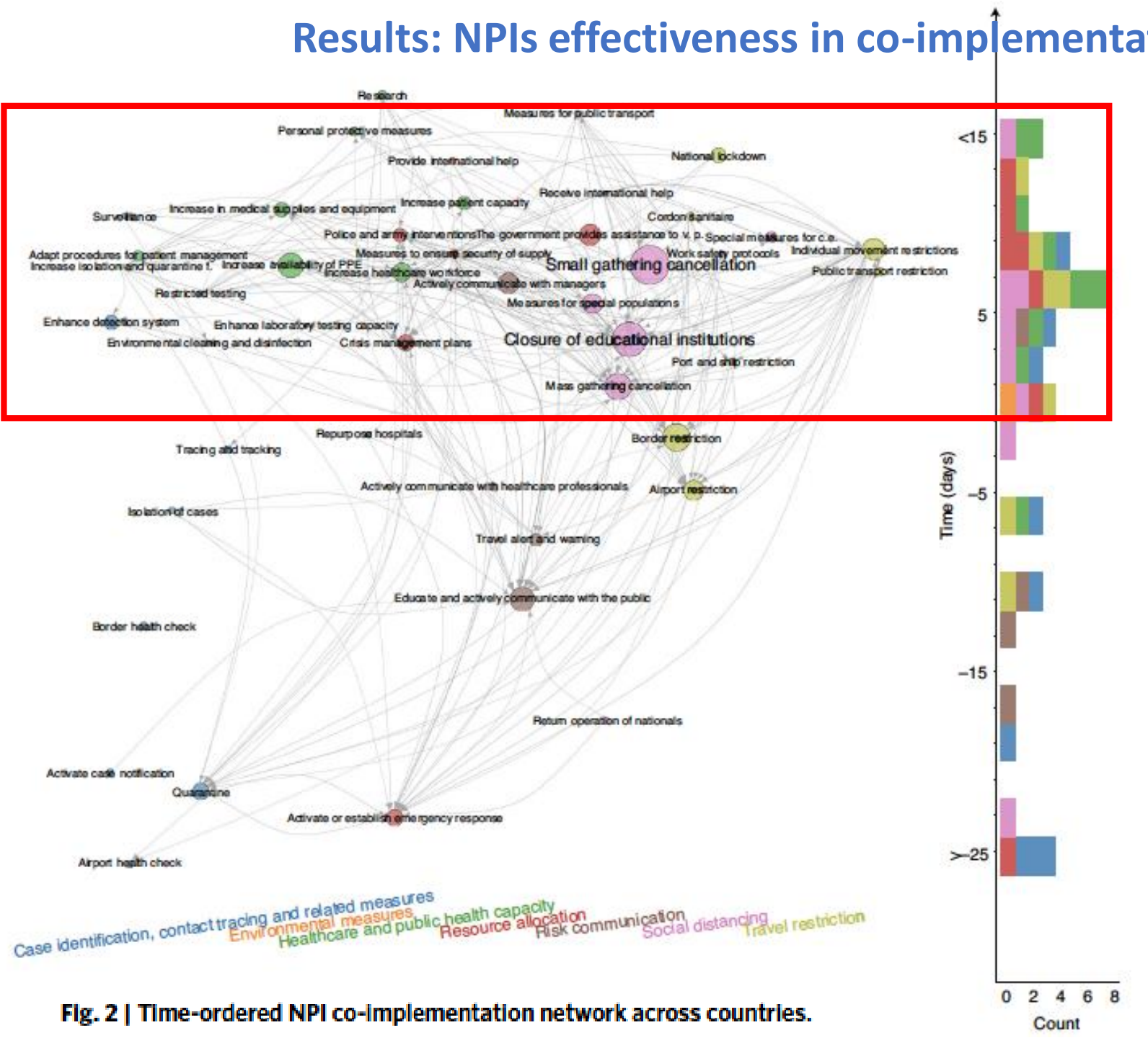


Fig. 2 | Time-ordered NPI co-implementation network across countries.

Nodes correspond to categories (L2)
Size proportional to average effectiveness of intervention
positioned vertically according to their average time of implementation

Arrows from nodes *i* to *j* indicate that countries which have already implemented intervention *i* tend to implement intervention *j* later in time.

Most of the measures were implemented **within the 2 first weeks** after reaching 30 cases, with varying impacts on R_t.

Results: NPIs effectiveness in co-implementation network

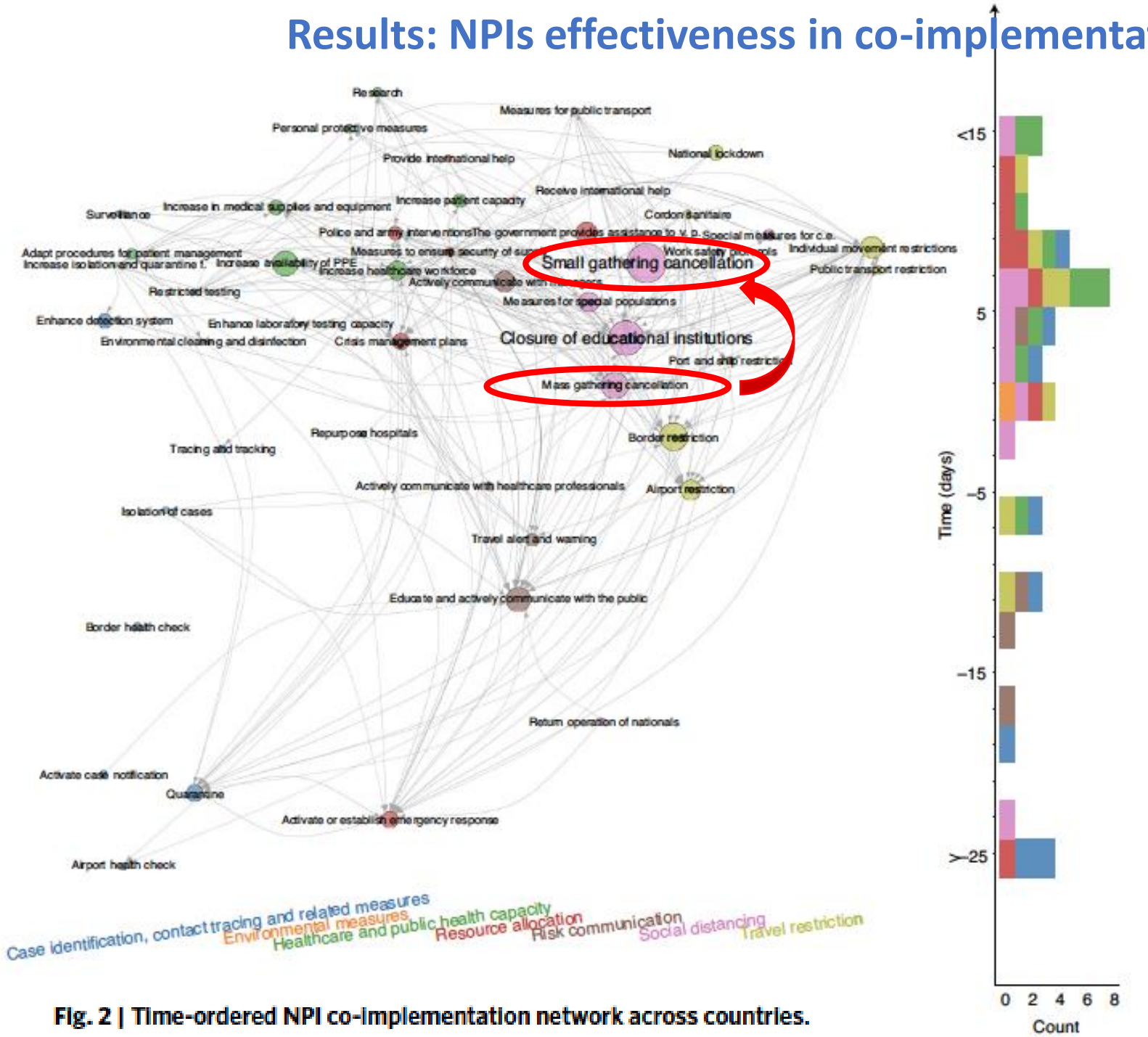


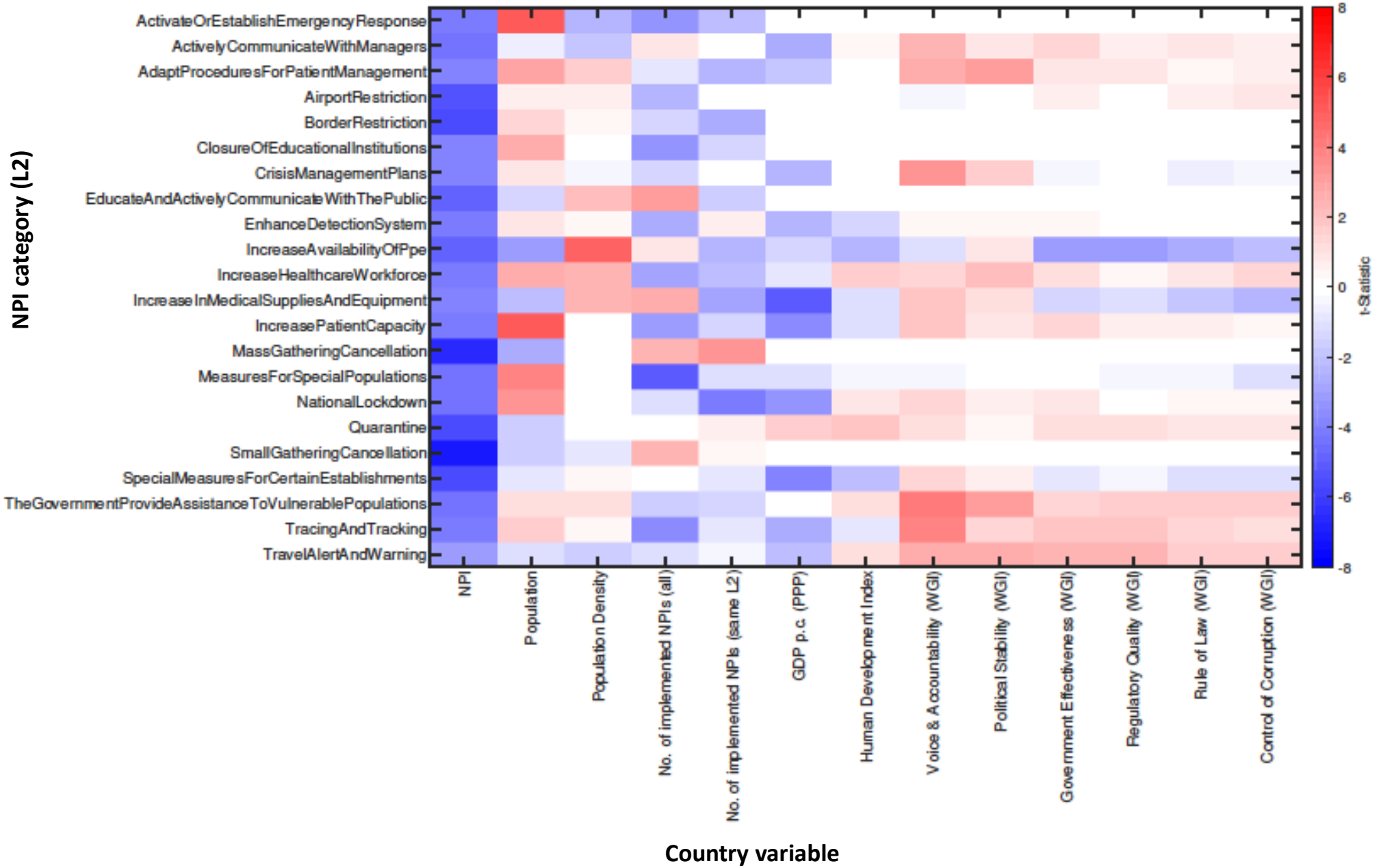
Fig. 2 | Time-ordered NPI co-implementation network across countries.

Nodes correspond to categories (L2)
Size proportional to average effectiveness of intervention
positioned vertically according to their average time of implementation

Arrows from nodes *i* to *j* indicate that countries which have already implemented intervention *i* tend to implement intervention *j* later in time.

Usually, countries **first cancel mass gatherings before moving on to cancellations of specific small gatherings**, where the latter associates on average with more substantial reductions in R_t

Results: country-level approach

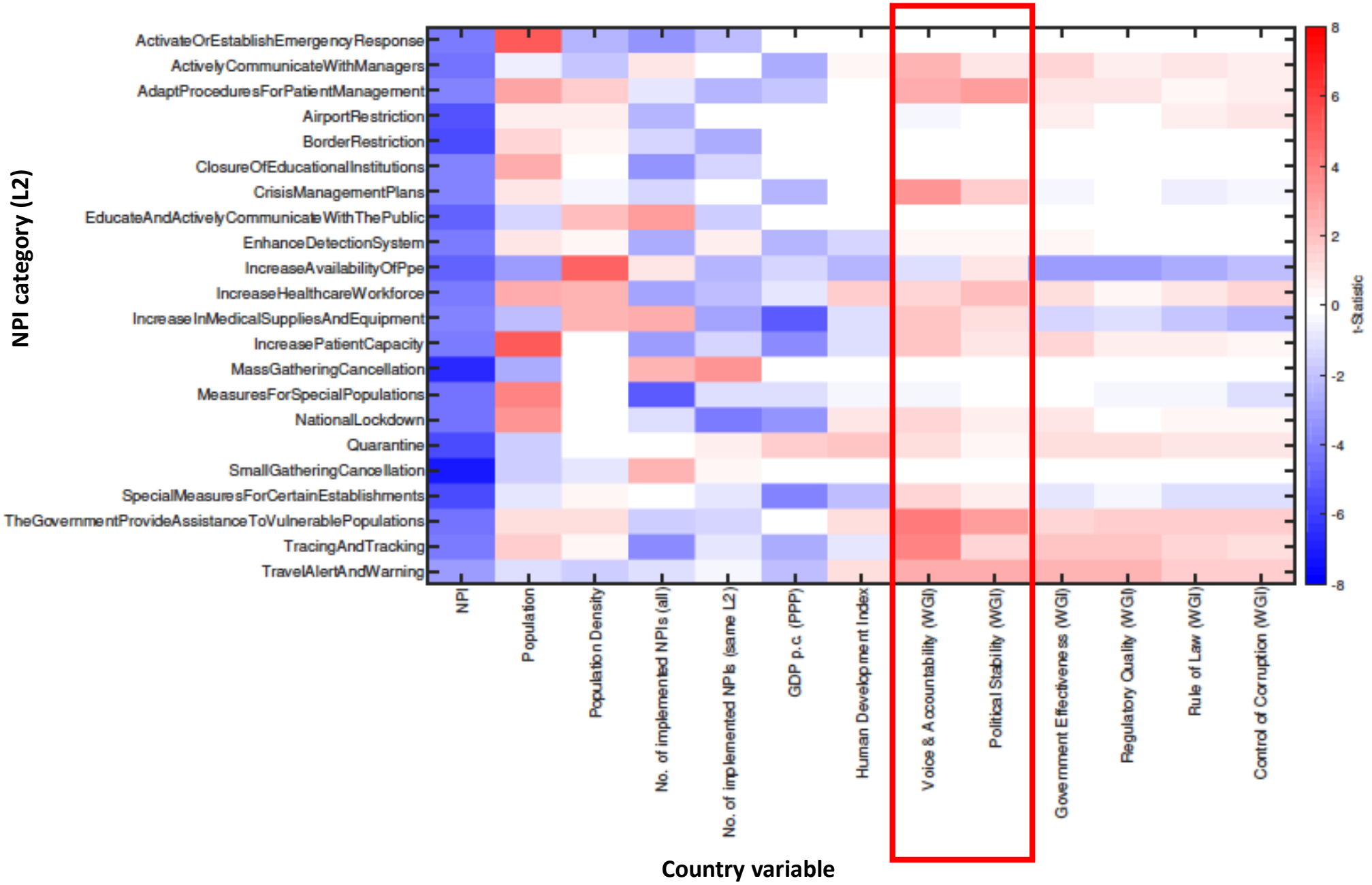


Impacts of country variables on *M* effectiveness.

The heatmap gives the average effect size (t-statistic) for a given NPI category (L2) and a country variable.

Blue (red) colour indicates that the variable is positively (negatively) correlated with measure effectiveness.

Results: country-level approach



Impacts of country variables on *M* effectiveness.

The heatmap gives the average effect size (t-statistic) for a given NPI category (L2) and a country variable.

Blue (red) colour indicates that the variable is positively (negatively) correlated with measure effectiveness.

Negative correlation of *M* effectiveness with indicator values for governance-related accountability and political stability.

Results: country-level approach

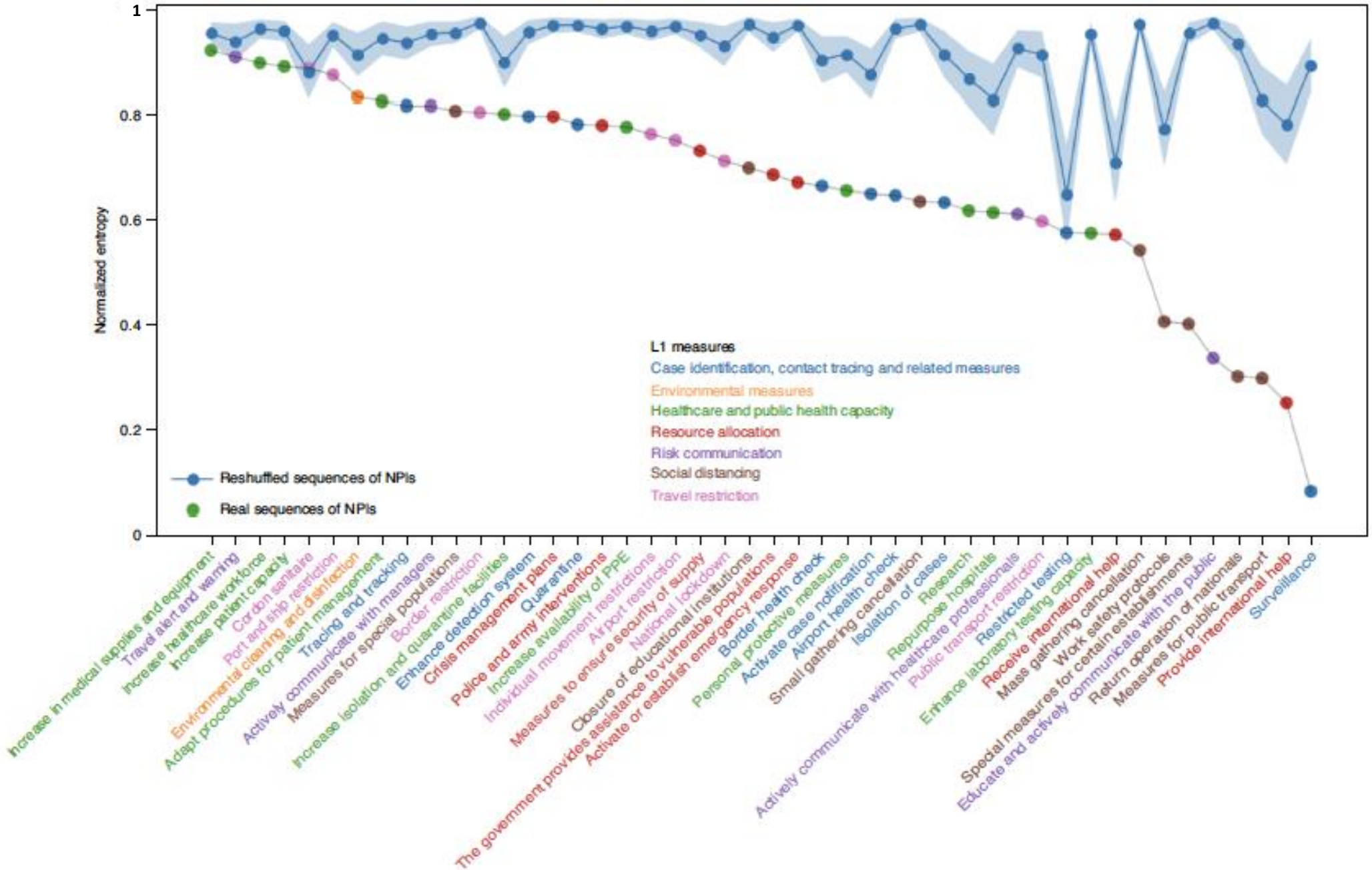


Fig. 3 | Normalized entropies versus rank for all NPIs at level L2.

Blue curve: entropies obtained from a reshuffled dataset of NPIs.

A value of entropy close to zero implies that the corresponding NPI has a similar rank relative to all other NPIs in other countries.

Results: country-level approach

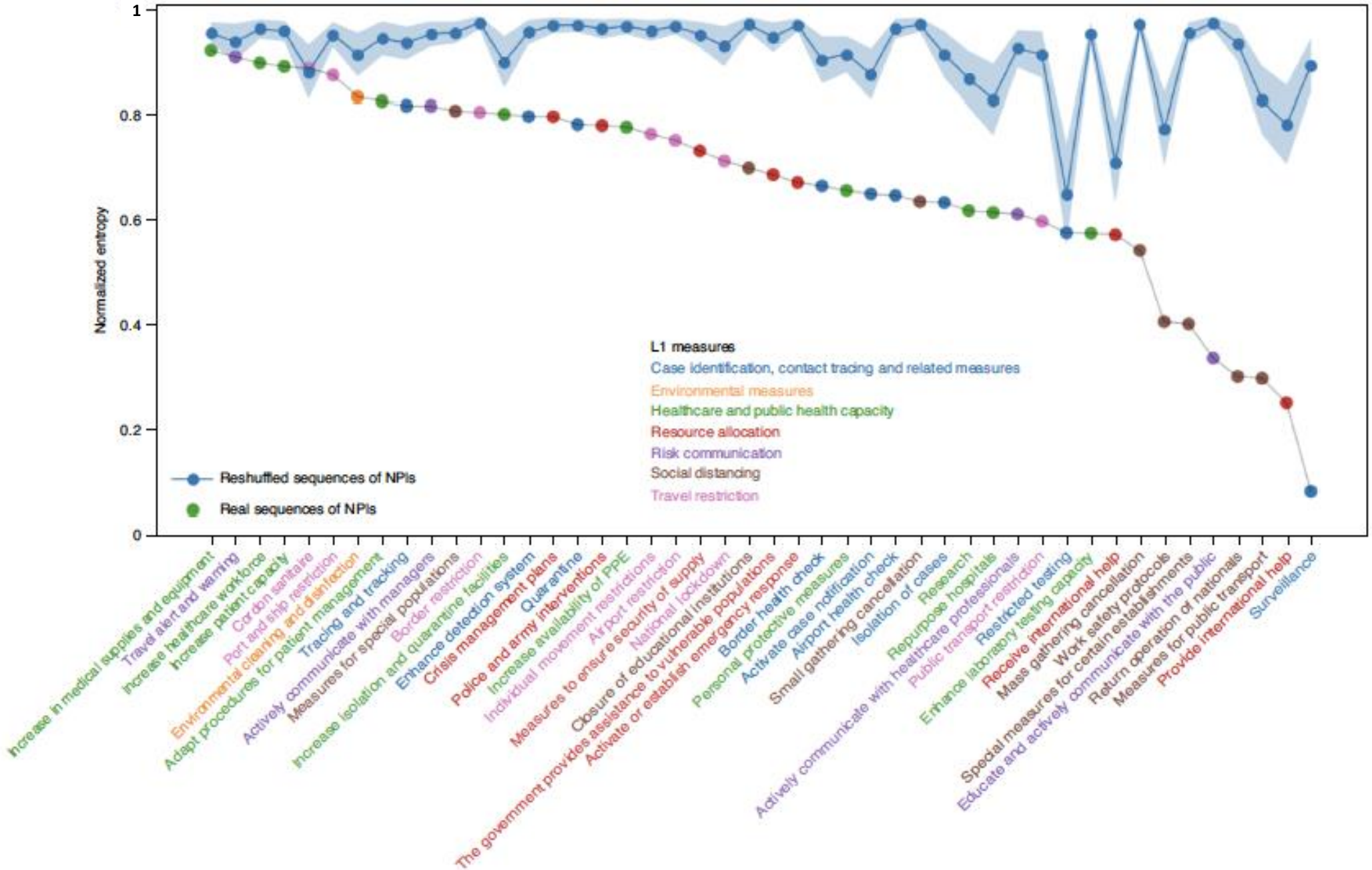


Fig. 3 | Normalized entropies versus rank for all NPIs at level L2.

Blue curve: entropies obtained from a reshuffled dataset of NPIs.

A value of entropy close to zero implies that the corresponding NPI has a similar rank relative to all other NPIs in other countries.

The values of entropy for many NPIs are far from one and are bellow the corresponding value after temporal reshuffling of NPIs in each country.

Results: country-level approach

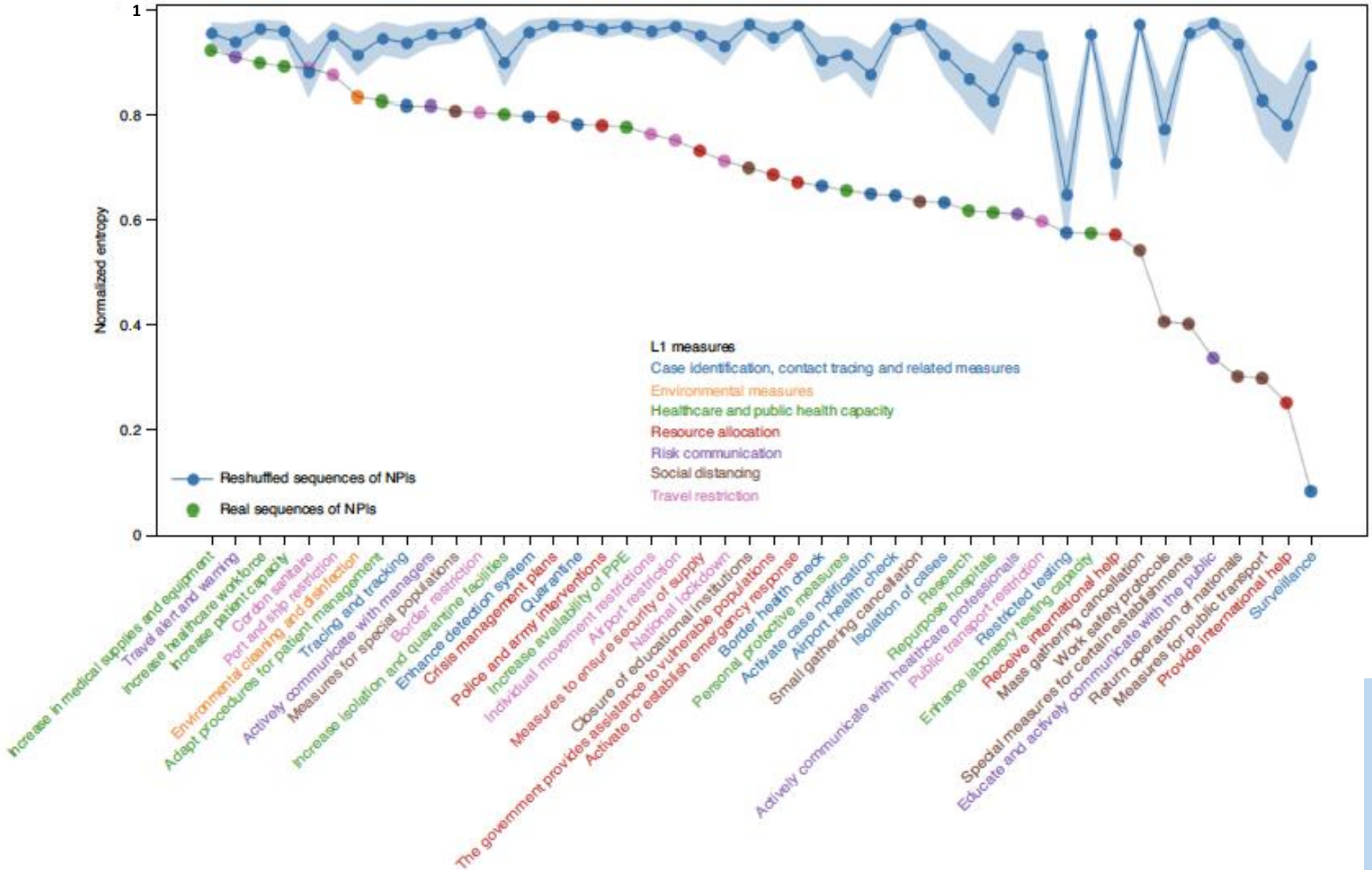


Fig. 3 | Normalized entropies versus rank for all NPIs at level L2.

Blue curve: entropies obtained from a reshuffled dataset of NPIs.

A value of entropy close to zero implies that the corresponding NPI has a similar rank relative to all other NPIs in other countries.

The effectiveness of many NPIs is significant, and depends on the local context (socio-economic features and NPIs already adopted).

Results: country-level approach - “what-if” experiments

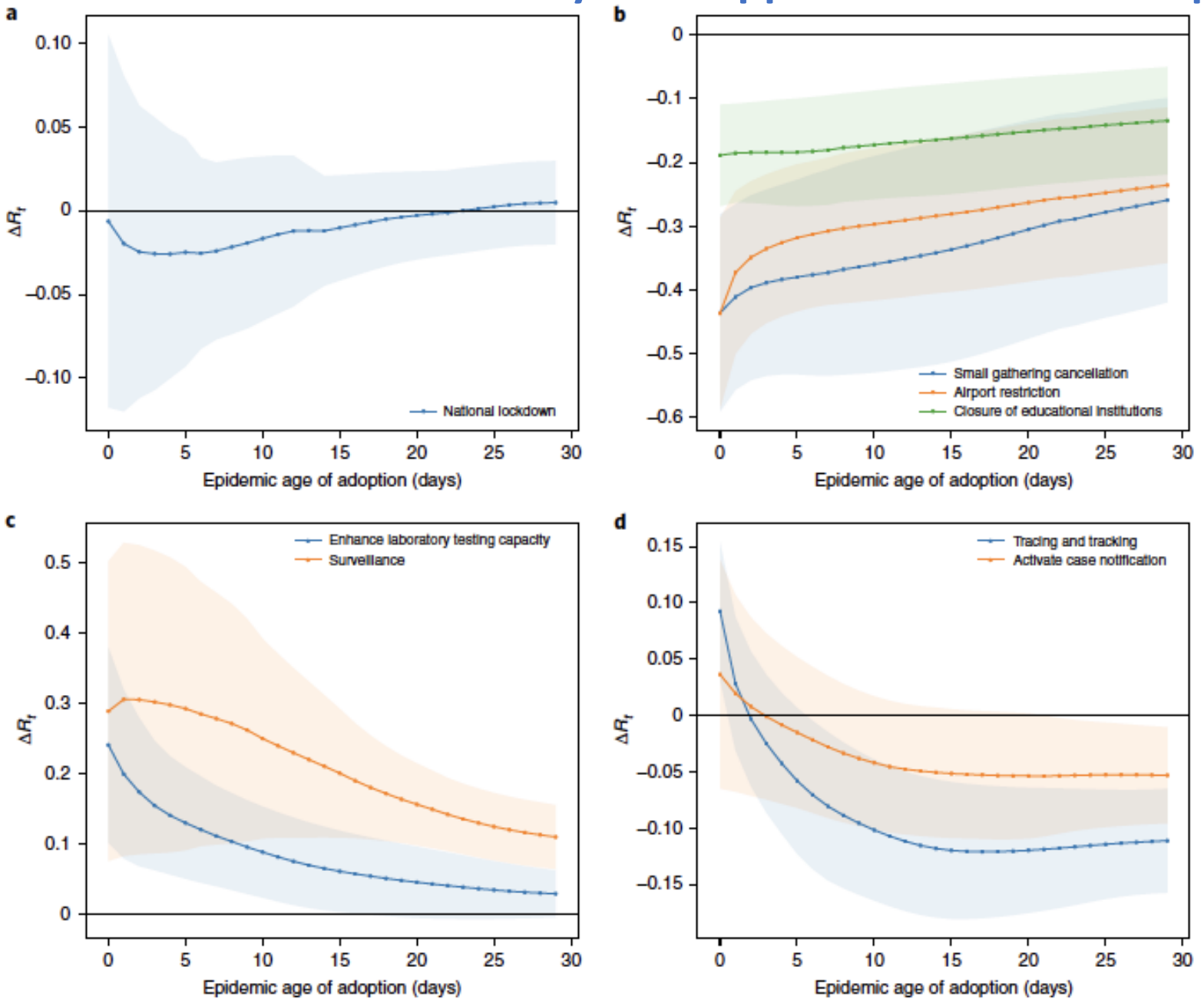


Fig. 4 | Change in R_t as a function of the adoption time of selected NPIs, averaged over countries where thosee NPIs had been adopted.

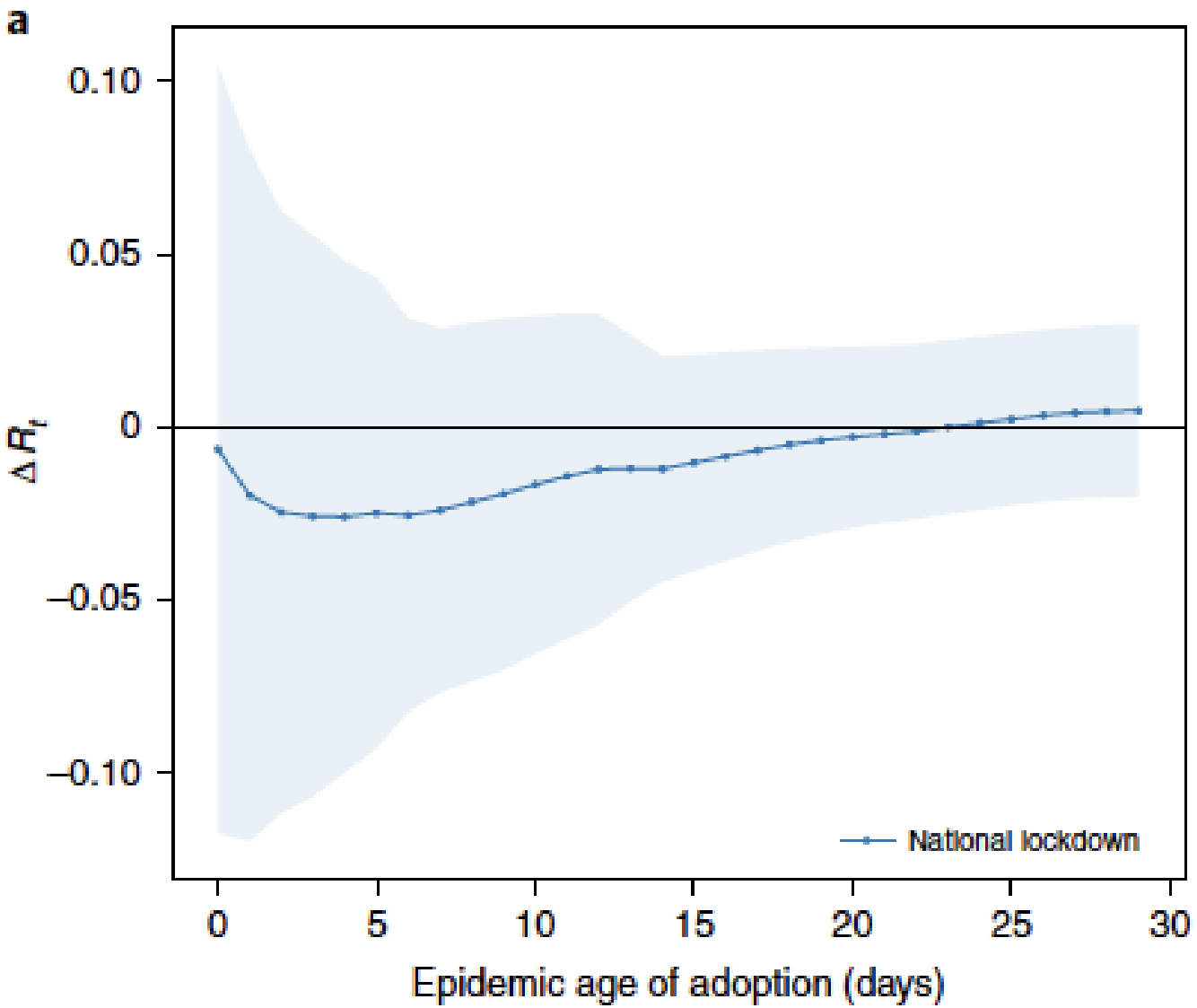
To quantify whether the effectiveness of a specific NPI depends on its epidemic age of implementation, artificial sequences of NPIs were constructed by shifting the selected NPI to other days while keeping the other NPIs fixed.

In this way, for each country and each NPI, a curve of the most likely change in R_t versus the adoption time of the specific NPI was obtained.

This figure shows the average change in R_t versus the adoption time of the NPI, averaged over the countries where that NPI was adopted.

Negative (positive) values indicate that the adoption of the NPI has reduced (increased) the value of R_t.

Results: country-level approach - “what-if” experiments



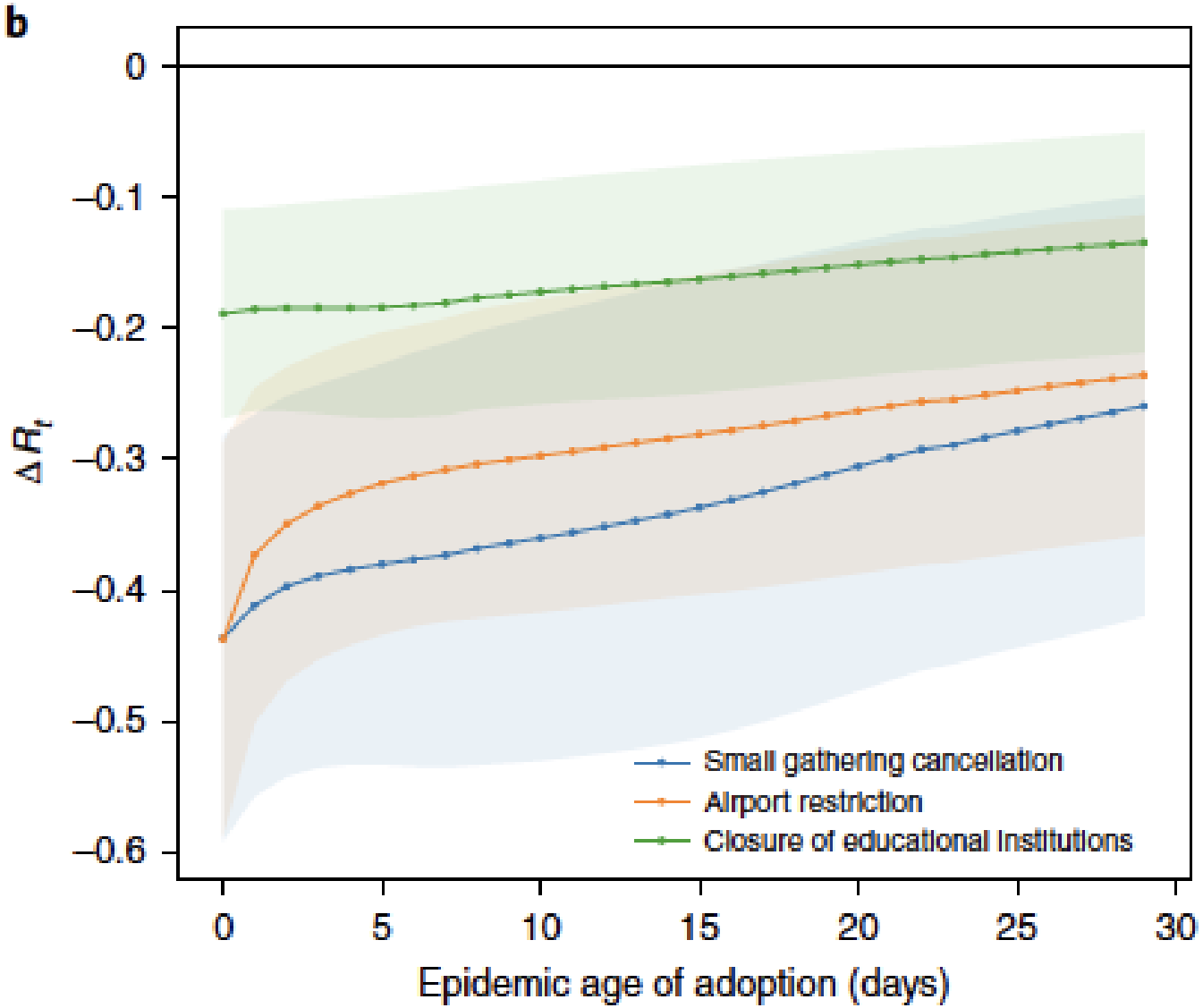
a. National lockdown

Moderate effect whenever the epidemic age of adoption

Very drastic measure with moderate effect on R_t

Fig. 4 | Change in R_t as a function of the adoption time of selected NPIs, averaged over countries where thosee NPIs had been adopted.

Results: country-level approach - “what-if” experiments



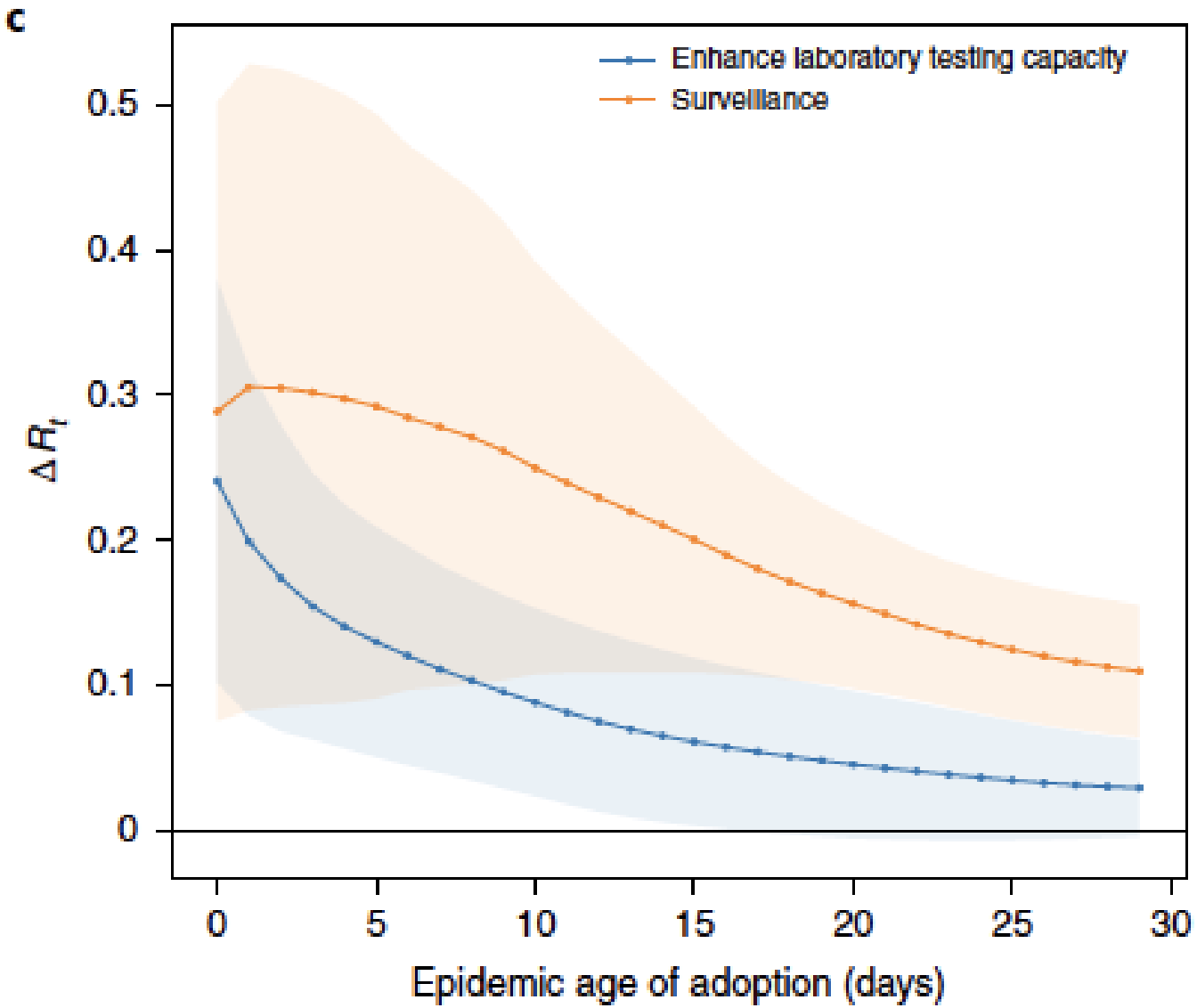
b. A selection of 3 NPIs displaying ‘the earlier the better’ behaviour

Small gathering cancellation
Airport restriction
Closure of educational institutions

Impact enhanced if implemented at earlier epidemic ages

Fig. 4 | Change in R_t as a function of the adoption time of selected NPIs, averaged over countries where thosee NPIs had been adopted.

Results: country-level approach - “what-if” experiments

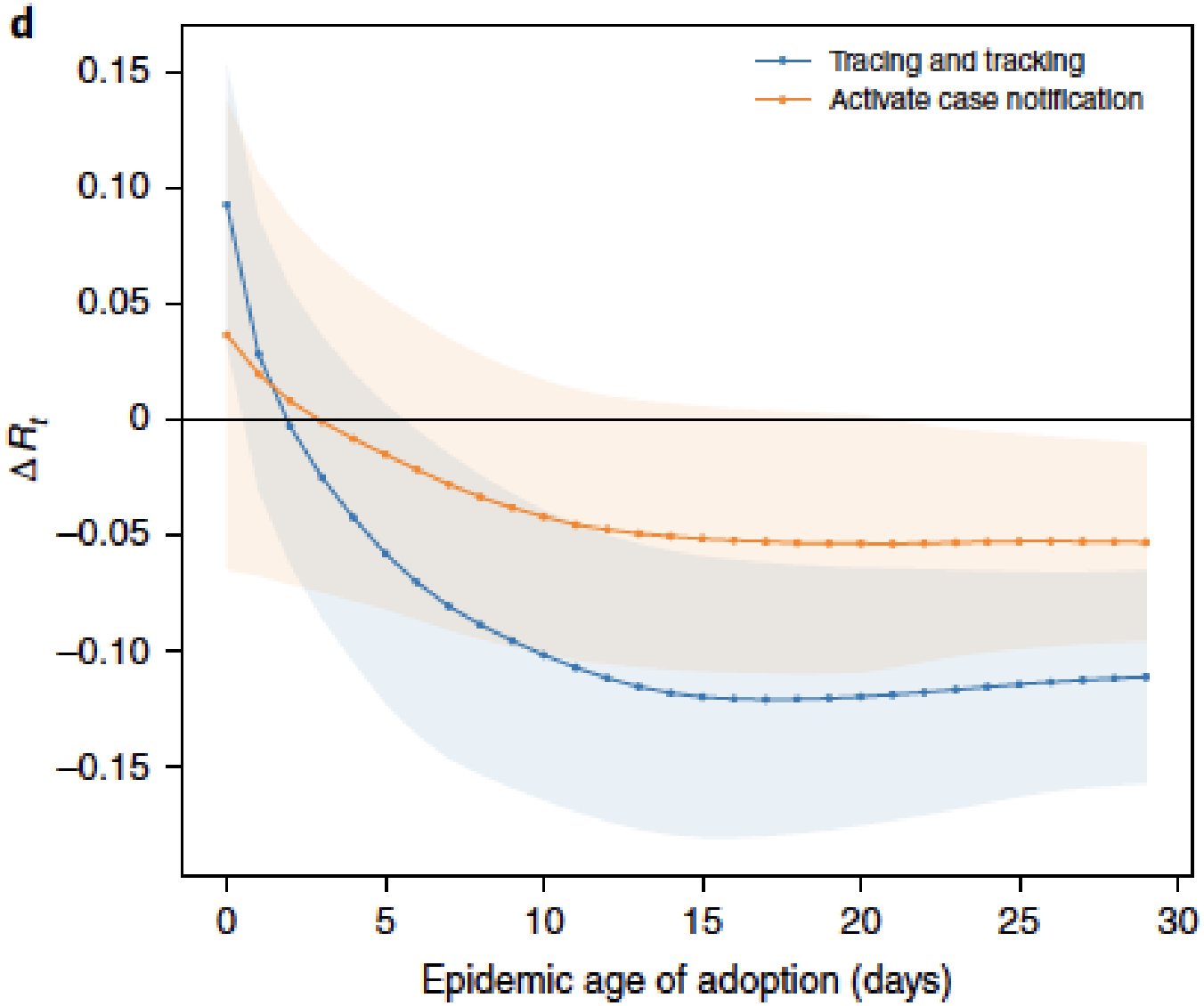


c. Enhance laboratory testing capacity and Surveillance

Negative impact because allows more cases identification?

Fig. 4 | Change in R_t as a function of the adoption time of selected NPIs, averaged over countries where thosee NPIs had been adopted.

Results: country-level approach - “what-if” experiments



d. Tracing and tracking and Activate case notification

Initial negative effect that turns positive after a few days

Fig. 4 | Change in R_t as a function of the adoption time of selected NPIs, averaged over countries where thosee NPIs had been adopted.

Conclusions

Findings validated by 4 independent methods → No NPIs act as a silver bullet on the spread of COVID-19

Several NPIs appeared efficient to decrease R_t
The most effective measures are very drastic:
curfew, lockdown, gathering prohibition… → Governments may have to look towards less stringent measures, encompassing maximum effective prevention but enabling an acceptable balance between benefits and drawbacks

Taken together, the **social distancing** and **movement-restriction measures** can be seen as the **'nuclear option' of NPIs**

Conclusions

Social distancing and movement-restriction measures
highly effective but causing substantial collateral damages to society, economy, trade and human rights.

Such radical measures have adverse consequences

School closure interrupts learning and can lead to poor nutrition, stress and social isolation in children [5-7].

Home confinement has strongly increased the rate of **domestic violence** in many countries, with a huge impact on women and children [8,9]

Home confinement has also **limited the access to long-term care** such as chemotherapy, with significant impacts on patients' health and survival chance [10,11]

(5) https://en.unesco.org/covid19/educationresponse/consequences
(6) https://www.oecd.org/coronavirus/policy-responses/education-and-covid-19-focusing-on-the-long-term-impact-of-schoolclosures-2cea926e/
(7) Orben 2020. The effects of social deprivation on adolescent development and mental health. Lancet Child Adolesc. Health 4,634–640
(8) https://www.nytimes.com/2020/04/06/world/coronavirus-domesticviolence
(9) https://www.forbes.com/sites/jackieabramian/2020/07/22/thecovid-19-pandemic-has-escalated-global-domestic-violence/#57366498173e;
(10) Tsamakis 2020. Oncology during the COVID-19 pandemic: challenges, dilemmas and the psychosocial impact on cancer patients (review). Oncol. Lett.20, 441-447
(11) Raymond 2020. Impact of the COVID-19 outbreak on the management of patients with cancer. Target. Oncol. 15,249–259

Conclusions

Lockdown encompasses multiple NPIs, including some already adopted when the lockdown is implemented

Mild effect due to an overlap with effects of other NPIs already adopted

This conclusion does not support the effectiveness of an early national lockdown,
but suggests that **a suitable combination** (sequence and time of implementation) **of a smaller package of measures can substitute for a full lockdown in terms of effectiveness**,
while reducing adverse impacts on society, the economy, the humanitarian response system and the environment

Not to mention vaccines not currently available and green pass not recommended at that time!

Thank you for your attention!

MUSE
MONTPELLIER UNIVERSITÉ D'EXCELLENCE

Pathogènes
Environnements
Hydriques
Santé

HSM

CHU
Département
D'Hygiène Hospitalière