Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Improving preparedness for next pandemics: Max level of COVID-19 vaccinations without social impositions to design effective health policy and avoid flawed democracies

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ABSTRACT

In the presence of pandemic threats, such as Coronavirus Disease 2019 (COVID-19) crisis, vaccination is one of the fundamental strategies to cope with negative effects of new viral agents in society. The rollout of vast vaccination campaigns also generates the main issue of hesitancy and resistance to vaccines in a share of people. Many studies have investigated how to reduce the social resistance to vaccinations, however the maximum level of vaccinable people against COVID-19 (and in general against pandemic diseases), without coercion in countries, is unknown. The goal of this study is to solve the problem here by developing an empirical analysis, based on global data, to estimate the max share of people vaccinable in relation to socioeconomic wellbeing of nations. Results, based on 150 countries, reveal that vaccinations increase with the income per capita, achieving the maximum share of about 70% of total population, without coercion. This information can provide new knowledge to establish the appropriate goal of vaccination campaigns and in general of health policies to cope with next pandemic impacts, without restrictions that create socioeconomic problems. Overall, then, nations have a natural level of max vaccinable people (70% of population), but strict policies and mandates to achieve 90% of vaccinated population can reduce the quality of democracy and generate socioeconomic issues higher than (pandemic) crisis.

1. Introduction

In the presence of pandemic threats, such as Coronavirus Disease 2019 (COVID-19) crisis, vaccination campaign can be one of the fundamental strategies to cope with new viral agents and to reduce the burden on healthcare system and negative effects in society (Akamatsu et al., 2021; Benati and Coccia, 2022; Coccia, 2021, 2021a, 2022, 2022a, 2021e; Núñez-Delgado et al., 2021). The rollout of vast vaccination campaigns also generates the main issue of hesitancy and resistance to vaccines in a share of people, which is a social aspect associated with individual freedoms in (rich and democratic) countries (cf., Coccia, 2022a, 2022b; Verger and Peretti-Watel, 2021). Many studies have investigated these topics to reduce hesitancy and increase the vaccinations in countries, such as Bullock et al. (2022) argue that vaccine hesitancy among people is due to anxiety rather than familiarity with vaccines. Patterson et al.2022 show that the acceptability of COVID-19 vaccine can be low because of issues concerning the uncertainty about safety of vaccines, the respect of personal rights, effectiveness of communication policies, etc. Kumar et al. (2022) argue that vaccine hesitancy has temporal and spatial variations associated with many socio-behavioral characteristics of humans, psychological responses of people towards COVID 19 pandemic and vaccination strategies of governments. The vast literature in these topics analyzes different aspects of vaccinations and societal reactions, nevertheless the maximum level of vaccinable people against COVID-19 without coercion in countries is hardly known but of utmost importance for effective health strategies to cope with next pandemic crisis.

The goal of this study is the development of an empirical analysis, based on global data, to estimate the maximum share of vaccinable people against COVID-19 (or in general against new infectious diseases) between countries without prescriptive approaches that undermine democracy, erode individual freedom and generate socioeconomic problems. This study can provide main information to support new knowledge to clarify the maximum threshold of vaccinable people in countries in order to set appropriate goals that improve vaccination plans without introducing rules of coercion (e.g., immunity certificates and/or vaccine mandates) that have a negative impact on the quality of democracy, freedom of people and performance of socioeconomic

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systems (cf., EIU, 2022). Hence, lessons learned from the study here can provide critical aspects to design effective health policies to cope with future pandemics, similar to COVID-19, with appropriate government responses that balance health of people, quality of democracy and economic growth of nations.

2. Methods

2.1. Sample

– The global analysis of this study is based on a sample of 150 countries.

2.2. Measures for statistical analyses

– Vaccination is measured by the percent share of people fully vaccinated against COVID-19 over September–October 2021. Data refer to all types of COVID-19 vaccines that are administered by countries to cope with negative effects of this new infectious disease on people and, as a consequence, healthcare sector. Source: Our World in Data (2022).
– Wellbeing of people is measured with the Gross Domestic Product (GDP) per capita in 2020 (constant in 2010 US dollars $). Source: The World Bank (2022).
– Degree of liberty and democracy in nations is based on Freedom House Index given by level of political rights and civil liberties within countries. Main categories of Freedom House Index are: a) free countries having a high level of the index that indicates a lot of political rights and civil liberties, low controls on public and private life of people; b) partly free countries and c) not free countries have a lower level of civil and political rights, a higher level of control and state interference on public and private life of people. Source: Freedom House (2021, 2021a).
– Stringency index is a composite measure of nine response indicators of government to cope with COVID-19 crisis (e.g., school and workplace closures; cancellation of public events; restrictions on public gatherings; stay-at-home requirements; government lockdown; restrictions on internal movements; international travel controls, etc.; Coccia, 2021c). The daily index is the average score of nine indicators, each having a value between 0 and 100 (100 = strictest response; cf., Hale et al., 2021; Stringency Index, 2022). Average values of stringency index considered in the study here is from January 2020 to January 2022 period between countries under study.

2.3. Model and data analysis procedure

– Levels of economic development of countries and wellbeing of people are categorized using GDP per capita in 2020 as follows (The World Bank, 2022):
  • HIGH level of economic development and wellbeing of people >$15,000
  • MEDIUM level of economic development and wellbeing of people ($2,000–14,999)
  • LOW level of economic development and wellbeing of people < $2,000

Data of countries are transformed, when necessary, in logarithmic scale for having normal distribution of variables and performing robust statistical analyses. The period under study of vaccination campaigns is September–October 2021 to calculate the normal level of people vaccinated between countries before the application of prescriptive approaches and coercion in some countries directed to increase the level of vaccinated people (Saban et al., 2021). The relationship of percent share of vaccinable people against COVID-19 between countries on wellbeing of people is based on following quadratic model that best fits the set of global data and considers non-linear effects into the relation under study:

$$\log y_{i,t} = \alpha_0 + \beta_1 \log x_{i,t-1} + \beta_2 \log x^{2}_{i,t-1} + u_{i,t} \quad (1)$$

where:

o $y_{i,t}$ = Share % of people fully vaccinated against COVID-19 over September–October 2021
o $x_{i,\ t\text{-}1}$ = GDP per capita in 2020
o $u_{i,t}$ = Error term
country $i = 1, \ldots, n$; t = time

The relationship [1] is estimated with the method of ordinary least squares. Mathematical optimization is applied on estimated relationship [1] to find the maximum level of share % of people fully vaccinated against COVID-19 in the sample under study. In particular, model [1] is applied both on countries with “free” status (according to Freedom House Index) that is a proxy of democratic and rich countries, and on total sample of countries ($N = 150$).

Finally, a comparative analysis of 12 selected countries having high and low levels of restrictions (measured with stringency index) to cope with COVID-19 pandemic crisis is performed for an in-depth analysis of the variation of socioeconomic indicators in nations (cf., Coccia, 2018). The sub-sample of 12 countries under study is categorized as follows:

a) countries with less prescriptive approaches of health policy and more individual freedom from state interference (Denmark, Finland, New Zealand, Norway, Sweden and the United Kingdom); average stringency index over 2020–2022 (January) period = 49.01
b) countries with more prescriptive approaches of health policy based on lockdown, immunity certificates, vaccines mandates and with a high degree of state interference on individual freedoms to cope with COVID-19 (Australia, France, Germany, Greece, Italy and Portugal). In particular, these countries have a high average stringency index over 2020–2022 (January) period = 62.97

Comparative analysis of two groups just mentioned is based on descriptive statistics of following variables: Stringency Index over 2020–2022 period; Quarterly GDP-Percentage change, 2020–2021 period; health expenditure % of GDP, 2008–2018 period; Mortality per 1,000 people in February 2022; Fatality rates % in February 2022 and Share % of people fully vaccinated against COVID-19 in February 2022 (description of variables is in Appendix A). Since the objective of countries is to reduce deaths of COVID-19, this control analysis can show if a public policy based on compulsory measures and coercion to increase the threshold of vaccinations beyond the estimated maximum here, it can effectively to decrease fatality rate in society.

3. Findings

Table 1 shows that in countries with high GDP per capita and having the status of partly free, the average share % of people fully vaccinated against COVID-19 is higher than free and not free countries; instead, in the set of countries having a medium level of income per capita, free countries have an average share % of vaccinated people higher than countries with a status of partly free and not free. This result shows that high economic wellbeing in more free countries can support a higher share % of vaccinations on total population.

Table 1
Descriptive statistics of the fully vaccinated people % per level of wealth in countries and degree of democracy.

Level of economic development and wellbeing of people based on average income per capita in 2020	Status of liberty and democracy in countries	Fully vaccinated September–October 2021		
		N	Mean (%)	Std. Error of Mean
HIGH > U$15,000	- FREE	36	63.99	10.39
	- PARTLY FREE	3	66.63	11.99
	- NOT FREE	4	59.65	18.14
MEDIUM (U$2,000–14,999)	- FREE	24	38.31	20.28
	- PARTLY FREE	24	28.71	18.36
	- NOT FREE	17	23.22	19.19
LOW < U$2,000	- FREE	6	7.42	8.32
	- PARTLY FREE	22	4.28	5.41
	- NOT FREE	14	13.69	19.86

Table 2
Parametric estimates of the model [1] of people fully vaccinated in 2021 on GDP per capita in 2020.

	SAMPLE OF *FREE* COUNTRIES	TOTAL SAMPLE OF COUNTRIES, $N = 150$
Constant α (St. Err)	−19.97*** (3.22)	−18.66*** (2.65)
Coefficient β_1 (St. Err.)	4.50 *** (.70)	4.194 *** (.62)
Coefficient β_2 (St. Err.)	−.209*** (.037)	−.192*** (.035)
R^2 (St. Err. of Estimate)	.73 (.49)	.67 (.904)
F	85.25***	144.95***

Note: Dependent (response) variable is: Share (%) of people fully vaccinated against COVID-19 over September–October 2021. Explanatory variable is: Gross Domestic Product per capita in 2020. Significance: ***p-value<0.001.

- Maximum level of vaccinations in FREE Countries

The estimated relationship of countries with FREE status, based on results of Table 2, is:

$$j_{i,t} = -19.97 + 4.50 w_{i,\,t-1} - 0.209\ w^{2}_{i,\,t-1}$$

The function is given by:

$$j(w) = -19.97 + 4.50\,w - 0.209\ w^2 \tag{2}$$

the necessary condition to maximize the function j(w) is:

$$\frac{dj}{dw} = j'(w) = 4.50 - 0.418w = 0$$

The first derivative equal to 0 is:

$$j'(w) = 0 \Rightarrow\ w^* = \frac{4.50}{0.418} = 10.76\ level\ of\ GDP\ per\ capita\ (in\ \log) = \$47{,}098$$

Now if we replace w^* in the equation [2], we have $j = 4.2525$ (in *log* scale), which is transformed by $e^j = 70.28\%$ indicating the max share of people fully vaccinated in *free* countries (Fig. 1).

- Maximum level of vaccination in the sample with all 150 countries

Estimated relationship [1] based on total sample of countries is (from Table 2):

$$q_{i,t} = -18.66 + 4.194 g_{i,\,t-1} - 0.192\ g^{2}_{i,\,t-1}$$

The function is given by:

$$q(g) = -18.66 + 4.194\ g - 0.192 g^2 \tag{3}$$

the necessary condition to maximize the function q is:

$$\frac{dq}{dg} = q'(g) = 4.194 - 0.384g = 0$$

The first derivative equal to 0 is:

$$q'(g) = 0 \Rightarrow\ g^* = \frac{4.194}{0.384} = 10.922\ level\ of\ GDP\ per\ capita\ (in\ \log) = \$55{,}374.53$$

The substitution of the value g* in the estimated relationship [3] produces $q = 4.2432$ (in *log* scale) that transformed with the exponential value (e^q), it generates the greatest level of people vaccinated in population between countries, given by 69.63% (Fig. 2).

Finally, 12 selected countries having high or low restrictions to cope with COVID-19 pandemic crisis are analyzed with a comparative analysis (Table 3). Results show that countries with high restrictions and obligations in society (average stringency index of 62.97) have a high share of people fully vaccinated against COVID-19 (in February 2022) equal to 77.17% (a very high value than natural maximum estimated here). Countries with less prescriptive approaches and more individual freedom from state interference for COVID-19 vaccinations (average stringency index of 49.01) have a lower percent share of people fully

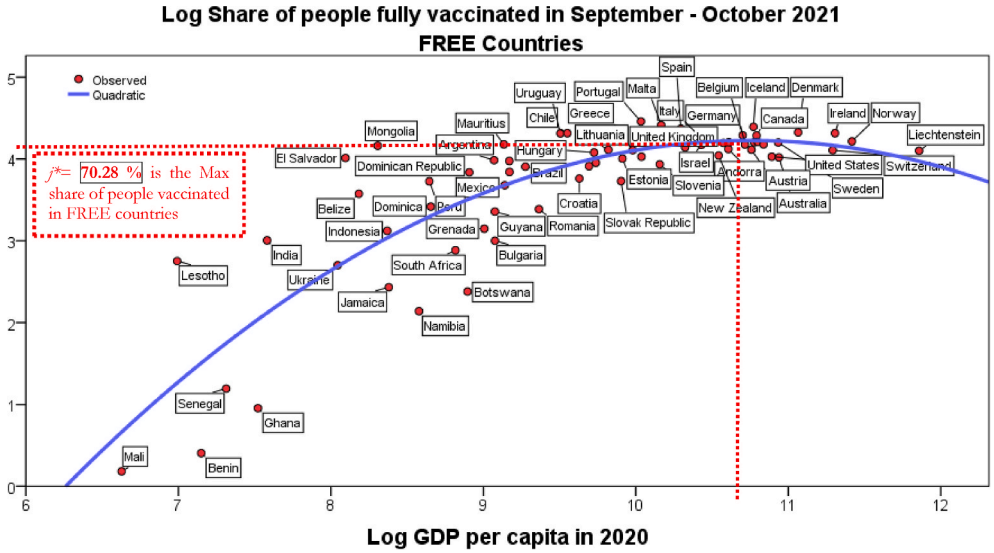

Fig. 1. The maximum level of 70.28% of vaccinated people in free countries.

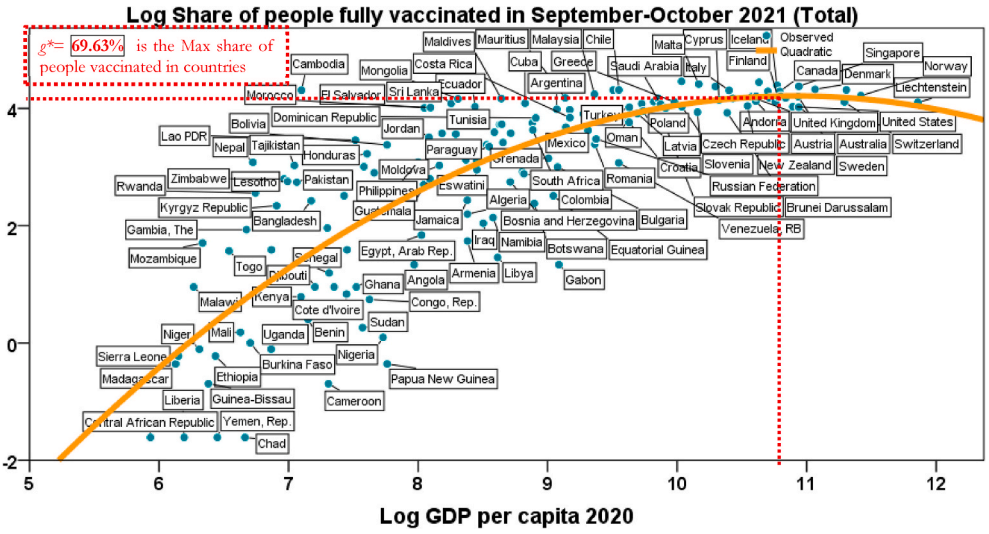

Fig. 2. The maximum level of vaccinated people (69.63%) based on full sample of countries.

Table 3
Descriptive statistics of countries with a high or low coercion for vaccination policy to cope with COVID-19.

	Countries with **HIGH** restrictions		Countries with **LOW** restrictions	
Description of variables	M	Std. Error Mean	M	Std. Error Mean
– Stringency Index over 2020–2022 period	**62.97**	**0.279**	49.01	0.282
– Quarterly GDP, Percentage change, 2020–2021	**0.14**	**1.05**	0.37	0.89
– Current health expenditure % of GDP, 2008–2018	**9.64**	**0.14**	9.70	0.086
– Mortality per 1,000 people, February 2022	**1.39**	**0.40**	0.89	0.37
– Fatality rates %, February 2022	**0.82**	**0.17**	0.43	0.12
– Share % of people fully vaccinated against COVID-19, February 2022	**77.17**	**3.00**	74.60	1.45

Note: M = arithmetic mean.

vaccinated (74.6%), closer to the max value estimated here. Results also show that countries having a stringent health policy with very high levels of vaccination than estimated max here of about 70% also have a mortality per 1,000 people and fatality rate (%) higher than countries with low restrictions and a share of total vaccinations closer to optimal value (estimated here): mortality ratio 1.19 *vs.* 0.89 and fatality rate 0.82 *vs.* 0.43, respectively. In addition, average quarterly GDP of countries, with a high score of stringency index (i.e., high restrictions for COVID-19 pandemic) and a very high level of vaccinations, is +0.14, the 64% lower than countries with a lower score of stringency index and lower share of vaccinations, which is close to optimal value (average quarterly GDP = +0.37). Comparative analysis of countries also shows similar average health expenditure (% of GDP) between these two groups. Overall, then, this finding reveals how compulsory measures to overcome the natural max level of vaccination (of about 70%) seem that do not reduce pandemic impact in terms of lower fatality rate of COVID-19 and generate negative effects for the operation of socioeconomic systems (and quality of democracy). In fact, many countries with high levels of containment policies to cope with COVID-19 have experienced a reduction of democracy index (cf., EIU, 2022).

Fig. 3 synthetizes these results: a very high share of vaccinated people against COVID-19 than optimal value estimated here (i.e., 70%) is associated with higher fatality rate and lower economic growth that generate a deterioration of socioeconomic system. This result suggests

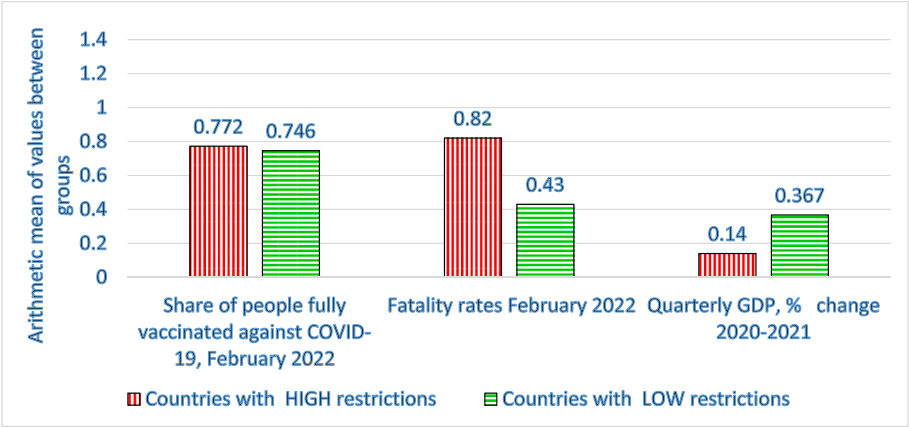

Fig. 3. Comparative analysis of health and economic indicators between countries with *high* and *low* restrictions to cope with COVID-19 pandemic crisis.

that the growth of vaccinated people, beyond the optimal threshold, using health policies of social coercion is not a sufficient strategy to reduce the negative impact of pandemic in society, because there are manifold factors that can support the diffusion and mortality of new viral agents (Coccia, 2022c).

4. Discussions and conclusions

Statistical analyses and mathematical optimization here suggest that the share of vaccinated people against COVID-19 increases with the wealth and wellbeing of nations, but it has a maximum level of about 70% between countries. Of course, the remaining share of about 30% is associated with a natural hesitancy of people to vaccinations (a social aspect underpinned in individual freedoms of modern society). This result is consistent with the study by Murphy et al. (2021) that find how adult populations of advanced countries (e.g., Ireland and the United Kingdom) had vaccine hesitancy/resistance from 31 to 35%. This level of vaccine hesitance and resistance that justifies the maximum level of vaccinated people estimated here (i.e., about 70% of total population) is in agreement with other studies, such as Neumann-Böhme et al. (2020) indicate in Europe about 26% of resistance to COVID-19 vaccines in adults, Malik et al. (2020) reveal that in the USA about 33% of people have hesitance to vaccinations, etc. This resistance to COVID-19 vaccines has similar rates for other types of vaccines, such as measles, mumps, and rubella (MMR) vaccines (Pew Research Center, 2015; Our world in data, 2020). Thus, in modern societies, more than 25% of people in population appears to be opposed to vaccinations concerning various infectious diseases and different types of vaccines (Murphy et al., 2021). Iyer et al. (2022) maintain that hesitancy is a main barrier to vaccinations to cope with negative effects of the COVID-19 pandemic in society. These scholars find that reluctant people can be persuaded to be vaccinated with a monetary incentive of about $1,000, whereas for unwilling individuals there is not any amount of monetary incentive that can persuade them to be vaccinated. Moreover, unwilling people do not trust of the public health system, government policies and tend to be individuals older than reluctant people (Iyer et al., 2022). Brown and Benson (2022) argue that vaccine hesitancy is one of the main health care challenges to cope with COVID-19, its variants and future infectious diseases.

The statistical evidence here, in a context of theoretical framework of hesitance to vaccinations, provides a main implication for an appropriate health policy to cope with pandemic impact:

- ☐ Nations have a maximum threshold of vaccinable people that is about the 70% of population because of normal vaccine hesitancy in modern societies.
- ☐ This study also suggests that strict health policies to overcome this maximum level with rules of coercion for the curtailment of individual freedoms (e.g., immunity certificates and/or vaccine mandates) reduce the quality of democracy and generate a negative impact on socioeconomic systems.

A more appropriate strategies to increase, whenever possible, the share of vaccinated people, can be based on communicating effectively with vaccine-hesitant individuals, using humble inquiry, compassionate listening, and storytelling, and engaging the entire health care staff in providing accurate information about vaccines and their side effects. Chan et al. (2022) describe many factors associated with vaccine hesitancy and propose that effective vaccination campaigns should be based on the implementation of mitigation plans and communication strategies. In general, the effectiveness of vaccinations is associated with levels of public trust in governments and correct communication that have to be reinforced in the presence of pandemic crisis, such as for COVID-19 (Echoru et al., 2021; Kanyike et al., 2021; Schwarzinger et al., 2021; Vergara et al., 2021; Verger and Peretti-Watel, 2021).

Overall, then, the main findings here are that the rate of vaccinated people increases with the income per capita between countries and it has a maximum level of about 70% of total population. Moreover, compulsory measures of countries to overcome this optimal threshold (equal to about 70% of population as estimated here) do not reduce pandemic impact in terms of lower fatality rates of COVID-19 but they can deteriorate economic growth and quality of democracy (Brown et al., 2021; Chantler et al., 2019; Dye and Mills, 2021; Kosciejew, 2021; Waitzberg et al., 2021; Wilf-Miron et al., 2021). In brief, this study suggests that the growth of vaccinated people beyond the optimal threshold, with rules of coercion, is not a sufficient strategy to reduce negative effects of pandemics because of manifold factors (e.g., psychological, sociodemographic, cultural, institutional, environmental and economic factors, etc.) in society driving infections and numbers of deaths (Ardito et al., 2021; Bontempi et al., 2021; Bontempi and Coccia, 2021; Coccia, 2017, 2017a, 2018a, 2020, 2021b; Coccia and Bellitto, 2018; Coccia and Rolfo, 2000; Pronti and Coccia, 2021, Coccia, 2022b, d).

Of course, these conclusions are tentative. Additional factors have to be examined to explain social, institutional and cultural barriers to the implementation of vaccinations in society and to clarify complex relations between level of vaccinations, COVID-19 mortality and related socioeconomic effects in the short and long run (Coccia, 2021d). These findings here highlight the importance of understanding the different social, economic, political, and psychological factors that can affect pandemic crisis to design effective health policies that maximize people vaccinated, without coercion, and reduce numbers of deaths. To conclude, it is worth raising in science the question, based on results here, whether in rich and democratic countries, ambiguous health policies to increase the percent share of vaccinations with coercion beyond the maximum of 70% and towards the threshold of 90% of population, they have generated more hazardous effects in society than infectious diseases with a reduction of freedom, equity and consequential deterioration of socioeconomic systems.

Declaration of competing interest

The author declares thathe has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. This study is not funded.

Appendix A

Indicators for comparative analysis between countries with high or low stringency of government responses:

- Quarterly gross domestic product total, percentage change, previous period, based on quarterly national accounts. Sources: OECD Data (2022). Period 2020–2021
- Health expenditure (% of GDP). Estimates of health expenditures include healthcare goods and services consumed during each year. This indicator does not include capital health expenditures, such as buildings, machinery, IT and stocks of vaccines for emergency or outbreaks (The Word Bank, 2022a). Period 2008–2018 (last year available)

- Population 2020. All residents regardless of legal status or citizenship. The values are midyear estimates. Source: The World Bank (2022b).
- COVID-19 deaths. Total number of deaths in February 2022. Source of data: Johns Hopkins Center for System Science and Engineering (2022).
- Fatality rate is measured with Case Fatality Ratio % (on February 11, 2022) given by:

$$\text{Case Fatality Ratio (CFR)}\,\% = \left(\frac{\text{Number of deaths from COVID} - 19}{\text{Number of confirmed cases of COVID} - 19}\right) \times 100$$

- Mortality ratio per 1,000 inhabitants for a comparative analysis with CFR is:

$$\text{Mortality ratio per } 1,000 \text{ people} = \left(\frac{\text{Total number of deaths from COVID} - 19 \text{ at February 2022}}{\text{Total population in 2020}}\right) \times 1,000$$

Source of data: Johns Hopkins Center for System Science and Engineering (2022).

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