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To do or not to do? Technological and social factors affecting vaccine coverage

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Abstract

This paper investigates the role of crucial technological and social factors in enhancing or undermining vaccine coverage rates at the country level worldwide. Employing five country-level databases, it explores how different combinations of technology diffusion, that is, social media penetration, and social conditions, namely functional literacy and attitude toward science, affect the level of vaccine coverage. The analyses are based on two built ad-hoc longitudinal datasets of 36 and 40 countries worldwide, employing a fuzzy-set qualitative comparative analysis (fs-QCA) approach. The findings highlight how, at the country-level, the absence of high social media penetrations combined with an above-the-average level of functional literacy and positive attitude toward science, the level of vaccine coverage reaches the coverage recommended by health institutions and authorities.

Keywords: technological and social factors; vaccine coverage; social media penetration; functional literacy; attitude toward science; configurational analysis.

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1. Introduction

The recent COVID-19 pandemic has rekindled the debate about social media platforms' role in spreading information and often misinformation related to health issues (Islam, Laato, Talukder, & Sutinen, 2020). Several articles in renowned newspapers have recently emphasized the risks linked with the misinformation spreading on information technologies (i.e., Internet and social media) and the consequences for the collective well-being, especially in terms of COVID vaccination hesitancy (Ahuja, 2020). At the same time, they recognize that technological factors are just one aspect of the problem. Social factors such as literacy and attitude toward science are critical for managing the pandemic crisis and the actual vaccination plan (Manjoo, 2020).

Simultaneously, the vaccination plan against COVID-19 is a crucial solution for "flattening the curve" and trying to redress the heavy economic consequences of the only solution previously available, that is, lockdown (Debecker & Modis, 2021).

In a quite similar manner, the academic literature has already recognized and investigated three aspects linked with technological and social factors affecting vaccine hesitancy. First, is widely recognized the role of technological factors, namely social media, in spreading misinformation about the vaccine (Chan, Jamieson, & Albarracin, 2020; Kata, 2012) and, as a consequence, a significant impact on increasing vaccine hesitancy (Bertin, Nera, & Delouvée, 2020; Jolley & Douglas, 2014).

Concerning the role of social factors, some research has addressed the link between the level of literacy and its relationship with vaccine hesitancy but mainly with qualitative and conceptual studies (Biasio, 2017; Peretti-Watel et al., 2019). Furthermore, a recent study calls for more research to deepen our understanding of the link between literacy and vaccine hesitancy (Biasio, 2019).

Two recent studies have recently approached the issue with a quantitative approach. The first have found no significant direct relationship between the specific variable of "health literacy," measured as understanding health-related terms and knowledge of disease's signs and symptoms (Casigliani, Arzilli, Menicagli, Scardina, & Lopalco, 2020), and vaccine confidence. Nevertheless, the same study suggests that other types of cognitive bias should be investigated (Casigliani et al., 2020), biases that can be linked with the other form of literacy, such as critical reasoning (Dacey, 2020). Conversely, another study has found that health literacy about vaccine reduces some of the adverse effects of being exposed to misleading information on vaccination" (Wang, Zhou, Leesa, & Mantwill, 2018, p. 413).

Lastly, scant literature has focused on the role of attitude toward science at the societal level and vaccine hesitancy. The only quantitative study found suggests that a positive attitude towards vaccine science is positively and significatively related to positive attitudes towards vaccine (Chan et al., 2020).

Despite the increasing interest in academic research toward the role of technological and social factors related to vaccine-related attitudes and intention, at least four main gaps are still present.

First, almost all the studies have focused on individual-level perceptive attitudes (e.g., vaccine hesitancy, vaccine confidence) or behavioral intention towards vaccine. However, scant research has approached the issue with a quantitative approach to investigate the actual level of vaccine coverage.

Second, almost all the published research have addressed very narrow definitions of literacy, namely health literacy and vaccine literacy, which cannot capture the presence of other cognitive bias (Casigliani et al., 2020) nor the lack of critical reasoning. Both issues seem related to individuals' ability to undergo or react to social media misinformation (Islam et al., 2020).

Third, no research has addressed the role of population-level attitude towards science as a possible social factor related to vaccine coverage.

Lastly, to the best of our knowledge, no studies have addressed all these factors in comprehensive analysis to consider the possible interrelations among them.

This study investigates the following research questions to fill the four gaps mentioned above: *what are the combinations, if any, of technological and social factors associated with the level of vaccine coverage recommended by the health institutions at the country level?*

A conceptual background is proposed based on two main streams of vaccine attitudes and intentions literature, namely on (1) the role of technological factors, in particular social media, in influencing vaccine-related attitudes and intentions (Bertin et al., 2020; Jolley & Douglas, 2014), and (2) the role of social factors such as literacy (Biasio, 2017; Casigliani et al., 2020; Peretti-Watel et al., 2019) and attitude towards science (Chan et al., 2020). Results show that some combination of those factors leads to vaccine coverage recommended by the health institutions and authorities.

The remainder of the paper is organized as follows. Section 2 introduces the conceptual background and the theoretical proposition; Section 3 describes the research methodology, namely data collection and analysis; Section 4 presents the results; lastly, Section 5 is devoted to the discussion and conclusions.

2. Background

2.1 Technological factors linked with vaccine attitudes and intention: the crucial role of social media

From the very beginning, academic research on anti-vaccine movements and vaccine misinformation has immediately recognized the risks associated with the Internet to spread misinformation and create opinion polarization around vaccine safety (Clements, Evans, Dittman, & Reeler, 1999). More generally, several information and communication technologies (ICT) could be potentially linked with vaccine attitudes and intentions, such as online forums, blogs (Shelby & Ernst, 2013), or even WhatsApp messages, audios, and videos (Nsoesie & Oladeji, 2020).

Also, other traditional media such as television and books have been employed as a channel for vaccine misinformation (Kata, 2012), but definitely, almost all the research about vaccine misinformation and vaccine attitudes are focused on the role played by social media (e.g., Bertin et al., 2020; Islam et al., 2020; Jolley & Douglas, 2014).

Social media play a critical role in spreading misinformation about vaccine through the sharing of misinformation of their users (Islam et al., 2020; Puri, Coomes, Haghbayan, & Gunaratne, 2020) and the participation in online anti-vaccine groups located on social media platforms (Chiou & Tucker, 2018). Finally, several studies agree on showing that exposure to vaccine-related misinformation on social media is significantly related to an increase in vaccine hesitancy and a decrease in vaccine intention (Bertin et al., 2020; Chan et al., 2020; Puri et al., 2020).

Given all the previous evidence from the literature, this study suggests that high vaccine coverage penetration at the country level should be associated with the absence of a high social media penetration level.

2.2 Social factors linked with vaccine attitudes and intention

In addition to social media technology acting as a channel to spread misinformation about vaccine, at least two social factors are investigated in the literature about vaccine-related attitudes and intention: (1) literacy and (2) attitude towards science.

Regarding literacy, a reasonably developed stream of literature investigates the role of health literacy (HL) or the more specific vaccine literacy (VL) construct to understand if those types of literacy impact vaccine hesitancy, confidence, or intention.

HL can be defined as "the degree to which people have the capacity to obtain, process, and understand basic health information and services to make appropriate health decisions" (Ratzan, 2011, p. 228). In contrast, the VL concept embraces the same aspects of HL such as "education—and knowledge about immunizations" but "also developing a system with decreased complexity to communicate and offer vaccines as sine qua non of a functioning health system" (Ratzan, 2011, p. 229).

Academic literature has strongly claimed that, at the conceptual level, HL and VL should be correlated with a decrease in vaccine hesitancy and an increase in vaccine intention (Biasio, 2017, 2019; Rowlands, 2014). At the same time, empirical evidence about these links is not consistent, and the relationship between HL and vaccination is still unclear (Lorini et al., 2018). A very recent empirical study has found no significant correlation between the level of VL and vaccine hesitancy measured as confidence in vaccine (Casigliani et al., 2020); therefore, the authors suggest amplifying the model about VL. Accordingly, evidence from another quantitative study shows that "higher literacy levels could reduce some of the negative effects of being exposed to misleading information on vaccination" (Wang et al., 2018, p. 413), suggesting the presence of moderating rather than a direct effect.

Given the above-mentioned inconsistencies in the correlation between HL and VL, and vaccine attitudes and intentions, this study follows the calls to amplify the model about literacy (Casigliani et al., 2020) and address the role of education and critical thinking (Arede et al., 2019).

A very up-to-date development of a VL scale about COVID-19 vaccine suggests that vaccine literacy has to take into account the individual ability to find the suitable sources of information, retrieve the relevant information, and critically reflect on the retrieved information about COVID-19 (Biasio, Bonaccorsi, Lorini, & Pecorelli, 2021). However, this conceptualization is not new, because generally, all the studies about HL have started out from the general definition of "functional literacy," which includes basic reading skills and more complex information processing skills (Berkman, Davis, & McCormack, 2010). However, none have verified if the more general functional literacy impacts vaccine attitudes and intentions.

This study agrees on the central role of information retrieval and evaluation, but it stands out for two reasons. First, this study claims that the abilities to access, retrieve, integrate, interpret, reflect and evaluate information can be grouped and labeled in the more general definition of "functional literacy," defined as the "levels of skills that individuals or populations need in order to complete some specified real-life reading task" (Kirsch & Guthrie, 1977, p. 490). Functional literacy then represents the skills for "reading (comprehending printed materials) to obtain, retain, or maximize an end or goal which has "survival" value (Kirsch & Guthrie, 1977, p. 490); therefore, it can be conceptually linked with vaccination evaluation and choice given it encompasses real survival values. Second, the learning and development of functional literacy start from school education, and it helps face online misinformation at the education age (Tseng, 2018). Moreover, reading skills learned at education age are related to relevant skills throughout life (Paris, 2005). Therefore, this study claims that, at the country level, a higher level of functional literacy at education age should be associated with higher vaccination coverage at parental age.

There is a lack of studies concerning the role of the general attitude towards science and its link with vaccine attitudes and intentions, and only limited literature partially focused on this issue exists. The first research suggests that misinformation in the form of conspiracy theory about vaccine is correlated with a negative attitude toward vaccine science (Bertin et al., 2020). However, it does not address the overall attitude towards science nor the link between this latter and vaccine coverage.

Another empirical research based on big data from social media suggests that attitudes towards vaccine science could be related to vaccine attitudes and intentions (Chan et al., 2020).

Drawing on these limited empirical pieces of evidence, this study suggests that, at the country level, a positive attitude toward science should be associated with a higher level of vaccine coverage.

2.3 Combinations of technological and social factors supporting vaccine coverage

The conceptual background presented above suggests that high levels of vaccine coverage are potentially associated with high levels of two social factors: functional literacy and a positive attitude toward science. Conversely, high levels of vaccine coverage are potentially associated with the absence of the main technological factor related to vaccine hesitancy, namely social media penetration.

Since our conceptual background implies the existence of combinations based on the presence and absence of technological and social factors, it needs to be addressed with a configurational approach both to advance the theoretical proposition (Bullini Orlandi, Zardini, & Rossignoli, 2021; Mas-Verdú, Ribeiro-Soriano, & Roig-Tierno, 2015) and empirically analyze data (Torres & Augusto, 2020). Qualitative comparative analysis (QCA) is a configurational approach well suited to explore combinations of social and technological factors and their consequences at the country level (Torres & Augusto, 2020). Therefore, in line with the conceptual background presented above and the QCA approach, this study formulates the theoretical proposition as follows.

Proposition. *At the country level, high levels of vaccine coverage are associated with high levels of functional literacy, and positive attitude toward science, and the absence of high social media penetration.*

3. Research design

3.1 Conditions and data sources

Two datasets were employed to maximize the availability of empirical observations, to test whether the above proposition found empirical evidence at the country-level worldwide. Both datasets were ad-hoc built, integrating publicly available data from five sources to measure the following outcome and three conditions.

Vaccine coverage (VC): in order to measure the vaccine coverage at the country level, two choices were made. First, the most diffused and debated vaccination is chosen, namely, the measles immunization, which is involved in the long-standing misinformation spread about vaccine correlation with autisms (Wakefield et al., 1998). Second, to maximize data availability and consistency, the 2018 data, which display the lower level of missing data worldwide, were collected. Therefore, all the data about measles-containing-vaccine first-dose (MCV1) immunization were collected from the World Health Organization database.

Social media penetration (SMP): as a proxy of this technological factor, the authors chose to measure the penetration of the most relevant and widespread social media platform involved in vaccine misinformation, that is Facebook. This condition was measured with an ad-hoc index that calculated the percentage ratio of Facebook users in 2018 and the total population in the same year for each country. Facebook users in 2018 for each country were taken from a publicly available platform about social media demographics, and population data were drawn from the United Nations database World Population Prospect in 2018.

Functional literacy (FL): to measure the level of functional literacy at the country-level were employed data from the Programme for International Student Assessment (PISA), which is a worldwide study by the Organisation for Economic Co-operation and Development (OECD). In particular, it was chosen the measurement of overall reading skills that is the average of the three subscales: (1) access and retrieve, (2) integrate and interpret, and (3) reflect and evaluate. In order to find the data temporarily related to vaccine decision-making and then to coverage in 2018, for each country was taken the PISA score nearest in terms of year to the differences between the age of first child minus one year (the minimum recommended age for MCV1) and fifteen years that is the age in which PISA tests are submitted. After this calculation, the nearest PISA score was chosen country by country, and the final sample comprehends, depending on the age of the first child, PISA scores from 2000, 2003, 2006, and 2009. The PISA scores were retrieved from U.S. National Center for Educational Statistics, and the mean age of first child scores was taken from both OECD and United Nations databases.

Positive attitude toward science (PAS): to measure this condition, data from the World Value Survey 2017 were integrated. In particular, two items were selected, and the scoring reversed, given they were originally stated as a negative attitude towards science. Precisely questions Q160 ("We depend too much on science and not enough on faith") and Q161 ("One of the bad effects of science is that it breaks down people's ideas of right and wrong") were employed. They were scored from 1 to 10; therefore, they were reversed and averaged.

As mentioned above, in order to maximize the empirical observations' number in different countries, two datasets were created. The first, labeled as "dataset A," comprises VC, SMP, and FL data. The second, labeled as "dataset B," includes data about VC, SMP, and PAS. Besides maximizing the total number of empirical observations in terms of countries, this solution is well-suited to overcome the limited diversity issue (see section 4.2).

3.2 Method

Data were analyzed with a fuzzy-set QCA approach (Ragin, 2008). The fs-QCA is a specific application of QCA permitting to attribute to each observation a non-dichotomous membership in different conditions' sets (i.e., technological and social factors) and outcome set (i.e., high vaccine coverage). The non-dichotomous membership indicates that each observation can be a member or non-member in a set of the conditions and outcome with a graded level of membership between full-membership (value 1) and full-non membership (value 0), the middle point is labeled maximum ambiguity point and set at 0.5 (see Berné-Martínez, Arnal-Pastor, & Llopis-Amorós, 2021). The fs-QCA approach is well-suited for analyzing non-linear and non-additive combinations of complex conditions at the country level (Furnari et al., 2020; Greckhamer, 2011). The fs-QCA analyses were performed employing the open-source software fs-QCA 3.0 developed by Prof. Ragin (2008).

The fs-QCA analysis requires three fundamental steps: (1) the calibration of conditions, (2) the analysis of the necessary conditions, and lastly (3) the analysis of sufficient conditions.

4. Analysis and results

4.1. Calibration of countries membership inside conditions and outcome sets

The first and more delicate phase in fs-QCA is the calibration of the membership of different countries for each input condition, namely social media penetration (SMP), functional literacy (FL), and positive attitude toward science (PAS). The membership in the output set was calibrated by employing the level of vaccine coverage (VC). This step is particularly delicate because calibration is a half-conceptual and half-empirical process to determine the cutoff points (also called thresholds or anchor points) for membership inside conditions and outcome sets (Greckhamer, Furnari, Fiss, & Aguilera, 2018). Therefore, the chosen processes, cutoff points, and the final membership scores should be transparently reported to permit readers to "evaluate validity and robustness of the calibration process and the resulting sets" (Greckhamer et al., 2018, p. 488).

As mentioned above, three cutoffs points were determined for full membership (set membership = 1), full non-membership (set membership = 0), and cross-over point or maximum ambiguity point (set membership = 0.5) to assign each country to the different conditions and outcome sets (Berné-Martínez et al., 2021). The calibration logic for each condition and outcome were the same in both datasets A and B and reported below. The results of calibration in both datasets are presented in Tables 1 and 2.

Vaccine coverage (VC): thanks to widespread analysis from health institutions, such as World Health Organization (WHO), and extensive scientific literature, the MCV1 vaccine coverage thresholds can be determined accordingly. This study chose as the cutoff point for high VC levels, the 95% coverage as the anchor for the full-membership. This percentage is considered necessary for measles elimination (World Health Organization, 2019). The maximum ambiguity point was set at 93% coverage, which is considered the minimum for preventing measles epidemics (World Health Organization, 2009). Finally, countries with coverage under 90% were considered in the full non-membership set, given 90% is considered the minimum level to reduce measles mortality (World Health Organization, 2009).

Social media penetration (SMP): given there is no theoretical concept that directly provides logics to define "high" and "low" level of SMP at the country level, this study applied the accepted practice of considering the relative level of each country compared to the overall sample in terms of percentiles (Berné-Martínez et al., 2021; Greckhamer & Gur, 2019; Torres & Augusto, 2020). In particular, we chose to assign the empirical value of the 75th percentile to the full membership, the value of the 50th percentile to the maximum ambiguity point, and the value of the 25th percentile to the full non-membership (Bullini Orlandi et al., 2021; De Crescenzo, Baratta, & Simeoni, 2020; Fiss, 2011).

Functional literacy (FL): in the case of functional literacy, given the present study wants to investigate the relative level of literacy at the country-level, both the above percentiles-based procedure and verification based on literature were employed. Once calculated the 75th, 50th, and 25^{th} percentiles, the empirical value of full-membership was compared to the PISA conceptual model of skills measurement. The 75th in the study sample corresponded to 506.25, which is coherent with being above the OECD average that is 500 (Stanat et al., 2002). The other two levels of 50th and 25th percentiles are based only on the relative distribution of the sample countries. However, they are coherent in representing countries with a functional literacy below the average.

Positive attitude toward science (PAS): attitude towards science was measured with the reversed average of two questions from the WVS 2017 survey as mentioned above. The distribution of the two WVS questions' average displayed a very high kurtosis and positive skewness; therefore, the determination mentioned earlier of cutoff points based on percentiles would be strongly biased. A different approach was then employed based on the 10 points Likert-type scale employed in the WVS survey. When Likert-type scales are employed, the middle value can be considered the point of maximum ambiguity (Fiss, 2011; Frambach, Fiss, & Ingenbleek, 2016) because it represents the statement "neither agree nor disagree." In WVS, the value 5 represents this maximum ambiguity point because the scale is from 1 to 10 and is anchored to agreement/disagreement statements. Given all the values are strongly "squeezed" (due to high kurtosis and positive skewness) near this value of 5, then this study considered all the values >5 as agreement and then as full membership. The countries displaying values <5 were considered as in disagreement and then in full non-membership. Robustness checks were performed in the following analytical phases to check if results would strongly vary, changing these cutoff points.

Table 1

Country membership dataset A.

Country	SMP	FL	VC
Albania	0.01	0.00	0.83
Argentina	0.99	0.07	0.83
Australia	0.91	1.00	0.54
Austria	0.01	0.72	0.83
Belgium	0.81	0.75	0.99
Brazil	0.80	0.04	0.00
Bulgaria	0.19	0.07	0.54
Canada	0.80	1.00	0.05
Chile	1.00	0.03	0.54
Czech Republic	0.05	0.44	0.99
Denmark	0.97	0.84	0.95
Finland	0.09	1.00	0.99
France	0.21	0.72	0.05
Germany	0.00	0.36	1.00
Greece	0.05	0.68	1.00
Iceland	1.00	0.87	0.54
Indonesia	0.05	0.01	0.00
Ireland	0.63	1.00	0.28
Israel	0.99	0.26	1.00
Italy	0.19	0.42	0.54
Japan	0.00	1.00	1.00
Korea	0.00	1.00	1.00
Latvia	0.02	0.20	1.00
Luxembourg	0.35	0.11	1.00
Mexico	0.95	0.13	1.00
New Zealand	0.97	1.00	0.28
Norway	0.97	0.94	0.99
Peru	1.00	0.00	0.00
Poland	0.01	0.35	0.54
Portugal	0.86	0.38	1.00
Romania	0.15	0.06	0.05
Spain	0.12	0.94	1.00
Sweden	0.90	0.97	1.00
Switzerland	0.01	0.47	0.99
Thailand	1.00	0.10	0.99
United States	0.90	0.95	0.28

Table 2

Country membership dataset B.

Country	SMP	PAS	VC
Andorra	0.80	0.00	1.00
Argentina	0.99	0.00	0.83
Australia	0.93	1.00	0.54
Bangladesh	0.02	0.00	0.28
Brazil	0.89	1.00	0.00
Chile	0.99	0.00	0.54
Colombia	0.95	0.00	0.95
Cyprus	1.00	0.00	0.05
Ecuador	0.99	0.00	0.00
Egypt	0.18	0.50	0.83
Ethiopia	0.00	0.00	0.01
Germany	0.16	1.00	1.00
Greece	0.43	0.00	1.00
Guatemala	0.28	0.00	0.00
Indonesia	0.42	1.00	0.00
Iraq	0.20	0.00	0.00
Japan	0.02	1.00	1.00
Jordan	0.68	0.00	0.28
Kazakhstan	0.01	0.00	1.00
Kyrgyzstan	0.01	0.00	0.99
Lebanon	0.68	0.00	0.28
Malaysia	1.00	0.00	0.99
Mexico	0.95	0.00	1.00
New Zealand	0.97	1.00	0.28
Nicaragua	0.28	0.00	1.00
Nigeria	0.01	0.00	0.00
Pakistan	0.01	0.00	0.00
Peru	0.99	0.00	0.00
Philippines	0.99	0.00	0.00
Romania	0.52	0.00	0.05
Russian Fed.	0.01	0.00	1.00
South Korea	0.09	0.00	1.00
Tajikistan	0.00	1.00	1.00
Thailand	0.99	0.00	0.99
Tunisia	0.95	0.10	0.99
Turkey	0.49	0.00	0.99
Ukraine	0.06	0.00	0.12
United States	0.94	1.00	0.28
Viet Nam	0.95	0.00	1.00
Zimbabwe	0.00	0.00	0.01

4.2 Analysis of necessary conditions

The analysis of the possible necessary conditions is the second step in fs-QCA for testing the empirical relevance of a theoretical proposition based on combinations of conditions.

In the present study, it means verifying if the membership (or non-membership) inside a condition's set (for example, in the set of high FL) is associated with the membership in the set of the outcome, that is, the set of countries with high vaccine coverage (VC). The fs-QCA studies often use the terms "presence" and "absence" of conditions (Torres & Augusto, 2020), which is the equivalent of displaying membership and non-membership inside conditions sets.

The necessary conditions analysis allows verifying if the presence or the absence (labeled with the tilde ~) of a condition is necessary for the presence (VC) or the absence (~VC) of the outcome. The conditions are necessary if their internal consistency is above the 0.9 thresholds (Schneider & Wagemann, 2012). Given that no condition has a consistency above 0.9 (see Table 3), none of the conditions is necessary to reach a high level of vaccine coverage at the country level. Seemingly, none of the conditions is necessary for the absence of vaccine coverage above 95%.

Table 3

Necessary conditions analysis in both datasets A and B.

Dataset A	VC		~VC	
Conditions	Consistency	Coverage	Consistency	Coverage
SMP	0.486	0.665	0.628	0.398
~ SMP	0.561	0.765	0.473	0.299
FL	0.581	0.757	0.534	0.322
~ FL	0.480	0.690	0.597	0.397
Dataset B	VC		~VC	
Conditions	Consistency	Coverage	Consistency	Coverage
SMP	0.628	0.398	0.560	0.504
~ SMP	0.473	0.299	0.500	0.488
PAS	0.534	0.322	0.218	0.474
~ PAS	0.597	0.397	0.792	0.472

4.3 Analysis of sufficient conditions

Even if no condition by itself is necessary for a country to be part of the set of high VC, fs-QCA also allows analyzing if combinations of conditions can be sufficient to be part of the outcome set (Ragin, 2008). One of the essential steps to run sufficient conditions analyses is to consider the issue of "limited diversity," comparing the number of all possible conditions' combinations with the empirical sample size (Soda & Furnari, 2012). The "limited diversity" issue occurs because the truth table (Ragin, 2008), which associates each country to a condition's set or not, consists of a 2^k number of possible combinations where k is the number of all the conditions considered. To give an example linked with the present study, if it is investigated whether SMP and FL are associated with high VC, this generates 2^2 possible conditions' combinations. Therefore, the chance to have enough cases to cover all four possible combinations is very high in dataset A made of 36 countries. And that goes for conditions in dataset B made of 40 countries. Conversely, creating a single dataset with the countries included in both datasets A and B would have been resulted in a dataset of only 13 cases and an analysis of 2^3 possible combinations, drastically increasing the issue of limited diversity.

T(Greckhamer et al., 2018)(Greckhamer et al., 2018)he following pieces of information about sufficient condition analysis are reported (see Table 4 and 5) to follow best practices in QCA analysis (Greckhamer et al., 2018): the truth tables with all the possible conditions' combinations the number of empirical cases associated with each combination, the raw consistencies, and the PRI or the proportional reduction in inconsistency (see Schneider & Wagemann, 2012).

The threshold of 0.8 in terms of raw consistency is employed (see Tables 3 and 4) to associate the empirically existing combinations with the VC outcome; this threshold is widely recommended in QCA literature (Greckhamer et al., 2018; Ragin, 2008). Furthermore, in both empirical datasets, the 0.8 raw consistency threshold is applied, also checking if the product between consistency and PRI of the conditions' combination is above 0.6 (Schneider & Wagemann, 2012).

4.4 Robustness analyses for sufficient conditions analysis

The analysis for the absence of high vaccine coverage (~VC) is presented to verify the robustness of the analysis of sufficient conditions. This analysis can partially confirm the results associated with VC outcome if mirror-like combinations of conditions are empirically associated with ~VC even if this cannot be taken for granted; the causal conditions associated with a negative outcome are not merely the opposite of those associated with the positive one (Ragin, 2008). Lastly, it was tested if changing PAS's calibration and employing the percentile-based cutoff points would impact the results. However, the analysis confirmed that the results are identical only with a small decrease in terms of raw consistency.

Table 4

Truth table for SMP and FL conditions (dataset A)

Causal Condition			Outcome	Consistency		
SMP	FL	Number	VC	Raw consist.	PRI consist.	Product
0	1	7	1	0.901	0.879	0.792
0	0	11	0	0.715	0.643	0.460
1	0	8	0	0.702	0.646	0.460
1	1	10	0	0.684	0.590	0.404
SMP	FL	Number	~VC	Raw consist.	PRI consist.	Product
1	1	10	0	0.437	0.271	0.118
0	0	11	0	0.426	0.282	0.120
1	0	8	0	0.398	0.283	0.113
0	1	7	0	0.278	0.121	0.034

Table 5

Truth table for SMP and PAS conditions (dataset B)

Causal Condition			Outcome	Consistency		
SMP	PAS	Number	VC	Raw consist.	PRI consist.	Product
0	1	4	1	0.836	0.822	0.688
1	0	16	0	0.616	0.574	0.354
0	0	15	0	0.503	0.456	0.230
1	1	4	0	0.338	0.106	0.036
SMP	PAS	Number	~VC	Raw consist.	PRI consist.	Product
1	1	4	0	0.735	0.642	0.472
0	0	15	0	0.561	0.519	0.291
1	0	16	0	0.443	0.381	0.169
0	1	4	0	0.244	0.178	0.043

A debate about sufficient conditions analysis results has recently been raised. QCA researchers are divided between those who claim that the intermediate solution has to be presented (Ragin, 2008;

Schneider & Wagemann, 2012) and those who criticized complex and parsimonious solutions suggesting to present the parsimonious solution which they consider the more representative of the underlying empirical data (Baumgartner, 2015; Thiem, 2019). In the present study, this issue is not present because there is no limited diversity, and all the possible conditions' combinations are associated with empirical observations (see the column Number in Tables 4 and 5); therefore, complex, intermediate, and parsimonious solutions are equal.

5. Results

The results of the analysis of the sufficient conditions suggest that different combinations of SMP, PAS, and FL are associated with reaching a vaccine coverage higher than 95%, that is, the presence of VC.

Conversely, no solution is consistently associated with the absence of an MCV1 higher than 95% (~VC); in fact, none of the possible conditions' combinations associated with the absence of VC have a raw consistency higher than 0.75 nor a product between PRI and raw consistency above 0.6 (see Table 6 and 7). Even if the empirical data do not provide evidence for a sufficient condition solution related to the negative outcome, they provide two sufficient condition solutions associated with an MCV1 coverage higher than 95%.

First, the absence of SMP and FL presence is consistently (consistency > 0.9) associated with VC. This solution is present in European countries such as Finland, Spain, Austria, France, and Greece, but also in two Asian countries, namely Japan and Korea.

This first solution is in line with the paper's theoretical proposition and conceptual background; in fact, the absence of a high level of social media penetration combined with functional literacy levels above the average leads to an MCV1 coverage higher than 95%.

Second, countries characterized by the absence of SMP and PAS's presence display a fairly consistent (consistency > 0.8) membership inside the set of countries with an MCV1 coverage higher than 95%.

These combinations of conditions mainly characterized Tajikistan, Japan, Germany, and Indonesia. This second solution also provides empirical evidence supporting the paper's proposition; in fact, the absence of high social media penetration in combination with the presence of a positive attitude towards science results in vaccine coverage at the recommended level.

Table 6

Sufficient conditions analysis for VC with SMP and FL

	Vaccine Coverage (VC)
Configuration	**Solution**
Social media penetration (SMP)	⊗
Functional literacy (FL)	●
Consistency	0.901
Raw coverage	0.358
Unique coverage	0.358
Overall solution coverage	0.358
Overall solution consistency	0.901
Countries with greater than 0.5 membership in the solution set: Japan, Korea, Finland, Spain, Austria, France, and Greece	

Notes: ● = Causal condition present ⊗ = Causal condition present

Table 7

Sufficient conditions analysis for VC with SMP and FS

	Vaccine Coverage (VC)
Configuration	**Solution**
Social media penetration (SMP)	⊗
Positive attitude toward science (PAS)	●
Consistency	0.836
Raw coverage	0.166
Unique coverage	0.166
Overall solution coverage	0.166
Overall solution consistency	0.836
Countries with greater than 0.5 membership in the solution set: Tajikistan, Japan, Germany, and Indonesia	

Notes: ● = Causal condition present ⊗ = Causal condition present

6. Discussion and conclusions

This study investigates the possible existence and composition of combinations of technological and social factors related to vaccine coverage at the country level. Previous research has already suggested three factors that could impact vaccine hesitancy, that are social media (due to vaccine-related misinformation spread), individual level of health or vaccine literacy, and attitude toward vaccine science. However, at the same time, this literature presents four relevant gaps. First, previous research focused almost entirely on individual-level subjective attitudes (e.g., vaccine hesitancy, vaccine confidence) or intention towards vaccine. Second, it has investigated very narrow definitions of literacy, such as health literacy and vaccine literacy, but more comprehensive literacy concepts, such as functional literacy, have not been addressed. Third, scant attention has received the role of positive/negative attitude toward science at the population level as a possible social factor impacting vaccine attitudes and intention. Lastly, no studies have addressed all these factors in a comprehensive theoretical and empirical analysis.

The present study has developed and analyzed, employing an fs-QCA approach, two longitudinal datasets of 36 and 40 countries worldwide integrating different data sources at the country-level to fill those gaps. The first gap is addressed employing an objective measure of vaccine coverage at the country-level, namely MCV1 coverage as measured by the WHO. This choice permits to effectively measure which country has reached, or exceeded, the scientifically grounded threshold of at least 95% coverage. The second and third gaps are faced analyzing functional literacy and positive attitude toward science as social factors at the country-level. Finally, the fourth gap is addressed by developing a broad conceptual background and theoretical proposition and empirically investigating it with an fs-QCA approach.

Results suggest that the proposed theoretical proposition finds empirical support at the country level. First of all, in both datasets, the solutions provide the absence of high levels of social media penetration to be inside the set of countries with coverage above 95%. Second, the presence of a functional literacy above the average and a positive attitude toward science is part of the solutions leading to the membership in vaccine coverage above the 95% threshold.

This empirical evidence confirms that social media are probably the most important means for spreading misinformation about vaccine and a critical factor unfavorable to vaccine coverage; in fact, the absence of high social media penetration is provided by both the founded solutions. With this claim, the present study does not want to suggest that it is better to reduce social media penetration, but indeed it emphasizes the importance of monitoring social media in terms of information/misinformation spreading about vaccine. Second, the empirical evidence supports the central role of social factors at the country-level, namely functional literacy and a positive attitude toward science. The critical role of functional literacy in reaching vaccine coverage above 95% addresses the claim to investigate other forms of literacy, besides health and vaccine literacy, which comprehend more general abilities to cope with cognitive bias and information processing. Furthermore, the present study had adopted a longitudinal perspective employing as a measure of the actual parents' functional literacy the level they had at the age of fifteen during high school. Therefore, the empirical results highlight the importance of high school education in functional literacy and critical thinking to face misinformation and make vaccine-related decisions.

Lastly, the importance of a population-level positive attitude toward science paves the way for furtherer investigation about the central role of educating and communicating the importance of science for the common well-being.

To conclude, this study is not free from limitations. It should be considered a first, significant step in studying vaccine coverage in terms of technological and social factors combinations with a macro-level perspective. Two main limitations are: first, the study only analyzes two datasets of 36 and 40 countries worldwide due to data availability, and second only the three main technological and social factors are considered. Future research could overcome this limitation by developing a survey with higher coverage in terms of the number of countries and types of conditions.

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