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ORIGINAL ARTICLE

COVID-19 vaccine acceptance: A comparative longitudinal analysis of the association between risk perception, confidence, and the acceptance of a COVID-19 vaccine

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Abstract

Following the outbreak of COVID-19, scientists rushed to develop vaccines to protect individuals and ferry the world out of the pandemic. Unfortunately, vaccine hesitancy is a major threat to the success of vaccination campaigns. Research on previous pandemics highlighted the centrality of perceived risk and confidence as core determinants of vaccine acceptance. Research on COVID-19 is less conclusive, and frequently it relies on one-country, cross-sectional data, thus making it hard to generalize results across contexts and observe these relationships over time. To bridge these gaps, in this article, we analyzed the association between perceived risk, confidence, and vaccine acceptance cross-sectionally at individual and country levels. Then, we longitudinally explored whether a within-country variation in perceived risk and confidence was correlated with a variation in vaccine acceptance. We used data from a large-scale survey of individuals in 23 countries and 19 time-points between June 2020 and March 2021 and comparative longitudinal multilevel models to estimate the associations at different levels of analysis simultaneously. Results show the existence of cross-sectional relationships at the individual and country levels but no significant associations within countries over time. This article contributes to our understanding of the roles of risk perception and confidence in COVID-19 vaccines' acceptance by underlining that these relationships might differ at diverse levels of analysis. To foster vaccine uptake, it might be important to address individual concerns and persisting contextual characteristics, but increasing levels of perceived risk and confidence might not be a sufficient strategy to increase vaccine acceptance rates.

KEYWORDS
confidence, longitudinal, multilevel, risk perception, vaccine hesitancy

1 | INTRODUCTION

Following the explosion of the COVID-19 global pandemic, scientists rushed to develop safe and effective vaccines. Less than a year later, vaccination campaigns started worldwide, but the vaccination process is less straightforward than anticipated. Researchers immediately identified vaccine hesitancy as a major threat to the success of vaccination campaigns (Dubé & MacDonald, 2020; Peretti-Watel et al., 2020). Recent contributions suggest, in fact, that whereas most of the population would accept a COVID-19 vaccine, a consistent number of individuals express refusal or hesitancy (Daly & Robinson, 2021; Freeman et al., 2020; Karlsson et al., 2021; Lazarus et al., 2021; Peretti-Watel et al., 2020).

While research on vaccine hesitancy received an off-the-scale impulse in the last 3 years, the topic has been at the center of academic and public health research for at least 15 years. These efforts identified a recurring set of elements influencing individuals' willingness to vaccinate and highlight, on one side, the relevance of contextual factors and, on the other, the primary role of attitudes and beliefs (see, e.g., MacDonald, 2015; Thomson et al., 2016). Indeed, research agreed on the importance of contextual determinants, such as the historical context, local health policies, or social and cultural norms, of organizational determinants such as the availability, affordability, and accessibility of vaccinations, and finally of individual determinants, such as knowledge, attitudes, and sociodemographic

characteristics (Dubé et al., 2015; MacDonald, 2015). Vaccine acceptance is therefore a complex issue standing at the intersection of individual decisions and societal needs, and it is heavily influenced by social, cultural, political, and historical factors (Dubé & MacDonald, 2020; Dubé et al., 2021).

Within this framework, perceived risk of infectious diseases and confidence in vaccines, health professionals, authorities, and institutions are central concepts in vaccine acceptance research. Indeed, research has shown multiple times the existence of a positive association between levels of perceived risk, confidence, and willingness to be vaccinated (Brewer et al., 2017; Floyd et al., 2000; Larson et al., 2015; Oster, 2018; Verger & Dubé, 2020). However, empirical results in the COVID-19 case are less conclusive. One limit of existing research is that it often relies on one-country, cross-sectional data, with only a limited fraction of studies relying on cross-country, longitudinal, or panel data (Brouard et al., 2022). This is understandable. In the face of an unprecedented situation, gathering time-sensitive information to understand the evolution of a pandemic is an invaluable asset. However, this comes with two consequences: First, it complicates the possibility of generalizing results across contexts and, second, it prevents the observation of whether these relationships covary over time.

In a later stage of the pandemic, researchers dedicated significant efforts to collect more encompassing data. New and existing panel studies directed their attention to the study of the pandemic (see, e.g., Brouard et al., 2022; Kittel et al., 2020), and researchers collected unprecedented large-scale data surveying individuals in tens of countries over many time points (see, e.g., Bacon et al., 2021; Hensel et al., 2022; Keng et al., 2022). Nevertheless, despite the availability of new longitudinal and cross-country data, we argue that one main limitation of existing research—with remarkable exceptions, see, for example, Fridman et al. (2021)—is that it does not exploit the features of such data to examine how relationships change over time. Relying on a large-scale data set collected by Facebook Inc. and the Massachusetts Institute of Technology (MIT) on 23 countries over 19 time points, from July 2020 to March 2021, we aim at addressing these gaps. First, we investigate if higher levels of perceived risk and confidence are associated with higher vaccine acceptance cross-sectionally at individual and country levels. Then, we explore whether a change in the perceived risk and confidence levels are correlated with a change in the willingness to be vaccinated within countries over time.

Understanding why people feel hesitant about COVID-19 vaccines is a fundamental tool for successfully implementing a large-scale vaccination program. Investigating whether established predictors of vaccine acceptance are relevant also in the case of COVID-19 across several contexts, and studying their covariance over time is a fundamental step to inform public policies and target individual concerns accurately.

2 | THEORETICAL FRAMEWORK

2.1 | The risk–vaccination link in cross-sectional, longitudinal, and COVID-19 scenarios

The way individuals perceive the risk of an infectious disease is a core determinant of vaccine acceptance. From an empirical perspective, before the COVID-19 pandemic, higher perceived risk of disease has repeatedly been associated with higher engagement with health-protective behaviors and vaccine acceptance, although with noteworthy contextual variability (Brewer et al., 2007). For example, in a large-scale study on the Measles, Mumps and Rubella (MMR) vaccine, Larson et al. (2016) showed significant country variability in acceptance rates, suggesting that the perception of a low risk of measles contributed to coverage gaps in several contexts.

Research on previous pandemics, such as the 2009 H1N1 swine flu pandemic and the Ebola outbreak (Gidengil et al., 2012; Vinck et al., 2019; Yang & Chu, 2018), underlined the positive association between levels of perceived risks and willingness to be vaccinated. In the COVID-19 case, research has suggested that the perceived risk of the disease is high across different contexts (Dryhurst et al., 2020) and positively correlated with vaccine acceptance (Attema et al., 2021; Freeman et al., 2020; Karlsson et al., 2021). However, it has shown noteworthy between-country differences in the specific dimension of risk correlated with vaccine acceptance. In a sample of, respectively, French and German respondents, Peretti-Watel et al. (2020) and Glöckner et al. (2020) found that willingness to be vaccinated was significantly associated with respondent's perceived likelihood of contagion, whereas Faasse and Newby (2020) showed only a marginal association between the likelihood of contagion, the severity of disease, and the willingness to be vaccinated in a sample of Australian respondents. Karlsson et al. (2021), studying Finnish respondents, concluded instead that only the perceived risk for the community was associated with intentions to be vaccinated. These slightly different results might indicate the existence of long-standing contextual characteristics that affect the relationship between perceived risk and vaccine acceptance in a heterogeneous way. In addition, the cross-sectional nature of the data and the rapidly changing pandemic situation might be relevant factors in explaining contextual specificities.

This notion raises the question of whether similar conclusions can be reached longitudinally, but empirical research showed mixed results. Gidengil et al. (2012), tracking the opinion of over 2000 U.S. panelists during the H1N1 pandemic, showed that perceived risk followed an inversed U-shape pattern, whereas willingness to vaccinate peaked at the beginning of the pandemic and steadily declined. Other studies on the same case reported either no correlation between perceived risk measured in a time point and willingness to vaccinate in a subsequent one (Li et al., 2012), or that while perceived risk increased, interest for

pharmaceutical preventive interventions steadily declined (Ibuka et al., 2010).

On the COVID-19 case, results depict a similarly complex scenario. Phillips et al. (2022), using a panel of respondents from the United Kingdom, found that willingness to vaccinate increased over time, whereas perceived fear and susceptibility to COVID-19 decreased. Qin et al. (2021) suggested instead that COVID-19 perceived risk and preventive actions showed positive within-time correlation, although the authors did not explore their covariance over time. To the best of the authors' knowledge, a study using a panel of respondents to analyze a within-unit change of perceived risk and vaccination intentions (Fridman et al., 2021), has shown that individual attitudes toward vaccination in the United States became less favorable over time, while the perceived risk increased, although only for participants who identified as democrats.

Additionally, scholars have observed that risks are perceived as more salient as a function of the assessed characteristics of the hazards they refer to. The analysis of the relationship between the perceived characteristics of a hazard and risk perceptions has a long tradition in risk analysis research, mainly originating from the work of Slovic (1987) and the development of the "psychometric paradigm." The author, analyzing the characteristics of a broad range of hazards, identifies two latent factors influencing an individual's perception of risk. The "unknown" risk factor underlines that risks are more salient when perceived as unobservable, new and unknown (Siegrist, 2021; Slovic, 1987). The "dread risk" factor (Slovic, 1987; Slovic & Weber, 2002), the most relevant of the two identified dimensions, highlights instead that a threat is perceived as more salient when is uncontrollable, dreadful, catastrophic, and with fatal consequences. One consequence of vaccine efficacy is a reduction of the number of cases of vaccine-preventable diseases that rendered the threat from vaccine-preventable diseases much less salient (Miton & Mercier, 2015; Omer et al., 2009). On a specular side, research shows that vaccination rates increase as a response to disease outbreaks (Oster, 2018). Therefore, it might be the case that the relationship between the perceived risk of COVID-19 and willingness to vaccinate is dependent on the level and change in the spread of the virus, and this relationship might also be influenced by preventive measures such as lockdowns that limit physical and social interactions (Attema et al., 2021). In the case of the H1N1 pandemic, while support for medical intervention steadily declined, perceived risk either paralleled the influenza activity (Gidengil et al., 2012) or increased (Ibuka et al., 2010). In the COVID-19 pandemic, Attema et al. (2021) showed that perceived risk constantly increased during a lockdown, while COVID-19 activity decreased, whereas in Italy both perceived risk and willingness to be vaccinated appeared to be increasing over time despite changes in the pandemic situation (Caserotti et al., 2021).

Although perceived risk and willingness to be vaccinated appear to be positively associated in cross-sectional studies, fewer studies investigate their covariation over time. Furthermore, mixed results emerge when investigating whether this association varies according to the pandemic situation.

2.2 | The confidence–vaccination link in cross-sectional, longitudinal, and COVID-19 scenarios

In research on vaccine hesitancy, the second core element of vaccine acceptance has often been associated with the word confidence. In risk analysis research, confidence usually represents the idea that a certain expectation will not be disappointed (Luhmann, 1988)—such as that you will not be hit by a car every time you leave your house—and a feeling of familiarity based on the idea that future events will happen as expected on the basis of past experiences (Earle, 2010; Siegrist, 2021, 2005). Trust, instead, emerges only as part of a decision-making process where a person opens up to the chance of taking a risk in the future (Earle, 2010), where the risk is that the trusted agent will not operate as expected. In the parallel literature on vaccine hesitancy, the word confidence has instead a more general connotation, and represents an "umbrella-term" that includes various dimensions of trust, such as beliefs that vaccines works, are safe and part of a trustworthy medical system (Brewer et al., 2017). Hereafter, we will refer to "confidence" when discussing this encompassing set of attitudes, whereas we will refer to trust when discussing a specific subdimension of confidence, such as trust in a specific agent.

Although confidence has often been recognized as one of the main determinants of vaccine acceptance, mixed results can be found in the literature because of conflicting definitions of the concept. The most widely accepted definition suggests that confidence involves dimensions of trust in the safety and efficacy of vaccines (the product), trust in the people administering the vaccines and other healthcare professionals (the providers), and trust in the motivations of those who make decisions on vaccines (the policy makers; Larson et al., 2015; MacDonald, 2015). More recent definitions stress instead the importance of also focusing on long-standing historical and sociopolitical contextual elements, highlighted by the role of trust in healthcare systems, science, and the sociopolitical context (Verger & Dubé, 2020).

Confidence plays a fundamental role in supporting individuals' decision to be vaccinated (Yaqub et al., 2014), while distrust in pharmaceutical companies, physicians, government, and researchers has been repeatedly connected with vaccine hesitancy (Majid & Ahmad, 2020). Hesitant individuals might think that pharmaceutical companies push a profit-oriented provaccine agenda (Dubé et al., 2015), that physicians might receive financial incentives to support vaccination (Attwell et al., 2017; Blaisdell et al., 2016), that governments could push policy interventions to favor vaccine uptake because of their ties with pharmaceutical companies (Helps et al., 2019), or that researchers could have withheld research results unfavorable to a provaccine agenda (Attwell

et al., 2017). Confidence levels have been positively associated with vaccine acceptance (Schmid et al., 2017) while showing a relevant contextual variability, and the European region has displayed significantly lower confidence than other areas of the world (Larson et al., 2016). Research on previous pandemics has supported these findings. High institutional trust was a fundamental component of vaccine acceptance during the 2018 Ebola outbreak (Vinck et al., 2019) and the H1N1 pandemic (Fabry et al., 2011; Rönnerstrad, 2016). This positive cross-sectional relationship seems to hold for COVID-19 as well. Trust in information from the government and health authorities (Lazarus et al., 2021), pharmaceutical companies (Phillips et al., 2022), institutions (Kreps et al., 2020), and researchers (Latkin et al., 2021) has been a strong predictor of willingness to be vaccinated. In cross-country samples, trust in public health organizations and key experts (Rozek et al., 2021), as well as trust in government, were associated with, respectively, higher vaccine acceptance and higher compliance with health-protective behaviors (Han et al., 2021).

As for risk perception, however, the confidence–vaccination link over time does not appear to be equally clear. Theoretical contributions have suggested that, in a pandemic, confidence is likely to decline over time because institutional competence is hardly tested when managing an unprecedented health crisis (Bangerter et al., 2012). During the 2009 H1N1 influenza outbreak, confidence peaked at the beginning of the pandemic and steadily declined over time. This change was correlated with growing public mistrust in the competence of governments and health authorities (Bangerter et al., 2012). Along the same line, Peretti-Watel et al. (2013) showed that distrust and vaccine hesitancy peaked at the end of the H1N1 pandemic, a situation that increased vaccine skepticism in the French population for several years (Verger & Dubé, 2020). Similar results have been found for the more recent 2018−2019 Ebola outbreak (Vinck et al., 2019).

As Verger and Dubé (2020) suggested, for COVID-19, we might assume that variation in vaccine acceptance might be correlated with variation in confidence following the evaluation of the pandemic management by healthcare personnel, systems, and governing bodies. Kritzinger et al. (2021) showed that institutional trust peaked at the beginning of the pandemic but quickly faded away, a result in line with the one from Palamenghi et al. (2020), who, studying a two-wave sample of an Italian citizen, highlighted that trust in science and scientific research declined over time. Unfortunately, to the authors' best knowledge, empirical contributions on the covariation of confidence and willingness to be vaccinated over time do not seem to be frequent.

It is perhaps an understatement to suggest that the COVID-19 pandemic has challenged the way individuals and societies deal with new risks and with the ways they were asked to have confidence in unprecedented measures to contain the virus. Empirical results show noteworthy contextual variability and rarely focus on longitudinal associations. Nevertheless, the possibility of generalizing results across contexts and observing whether these dimensions covary over time are fundamental information both from an academic and a public policy perspective.

In this article, we aimed to investigate these issues further by adopting a more extensive approach. The research questions driving this article are fourfolds.

Q1: Is there a cross-sectional relationship between levels of perceived risk, confidence, and willingness to be vaccinated?
Q2: Are long-standing between-country differences in levels of perceived risk and confidence associated with different country levels of willingness to be vaccinated?
Q3: Is a within-country change in the levels of risk and confidence associated with a within-country change in willingness to be vaccinated?
Q4: Does the association between a within-country change in the level of risk perception and the within-country change in willingness to vaccinate depend on a change in the within-country pandemic situation?

3 | DATA, VARIABLES AND METHODS

3.1 | Data

We relied on the Global Survey on COVID-19 beliefs, behaviors, and norms (Collis et al., 2022), a large-scale data set collected by Facebook, Inc., and the MIT, and advised by the Johns Hopkins Center for Communication Programs (CCP) and the World Health Organization Global Outbreak Alert and Response Network (GOARN). Using the Facebook app, over two million users in 67 countries and aged 18 years and older took part in an off-platform survey on several topics related to COVID-19. The selection of participants was based on individuals' sociodemographic characteristics and engagement with the platform by Facebook, which developed a sampling frame to decide who to administer the survey.

For 23 countries with a sufficient pool of users, every 2 weeks a new sample of respondents was invited to participate, resulting in a repeated cross-sectional survey spanning over 19 waves from July 7, 2020, to March 29, 2021. The surveyed countries were: Argentina, Bangladesh, Brazil, Colombia, Egypt, France, Germany, India, Indonesia, Italy, Japan, Malaysia, Mexico, Nigeria, Pakistan, the Philippines, Poland, Romania, Thailand, Turkey, Great Britain, the United States, and Vietnam.

At the beginning of the questionnaire, all participants were shown the same five blocks of questions, investigating, among others, sociodemographic information and willingness to be vaccinated. Each respondent was subsequently shown four random blocks from the others in the survey. For this reason, only a random subset of respondents were conjointly assigned to the two survey blocks containing information about perceived risk and confidence. Overall, 170,749 individuals were assigned to both question blocks. We have complete information for 142,264 individuals that

constituted our analytical sample. Descriptive tables reporting the distribution of missing data, and individual-level summary statistics by country and wave are available in the Supporting Information.

To minimize the representation error due to coverage, sampling variability, and nonresponse bias, the Facebook team designed a set of weights based on self-reported demographics and internal Facebook data. In this article, we used weights developed for the individuals who completed the sociodemographic block of the questionnaire and having as reference the 18 years and older population of each country. For a more extensive explanation of the survey's sampling selection, weights design and use, and the full questionnaire, see Collis et al. (2022) and Barkay et al. (2020).

To include in the analysis a time-varying indicator of the change of the pandemic, we relied on official governmental sources, collected in the publicly available data set "Our World in Data" (Ritchie et al., 2020). To include data on the level and variation of containment policies in each country over time, we used the publicly available data collected in the "Oxford COVID-19 Government Response Tracker" (OxCGRT; Hale et al., 2021). The data set collects a wide range of indicators on governments' policies and interventions during the pandemic, elaborated from publicly available data such as news articles and government press releases.

3.2 | Variables

In this section, we describe the main variables used in the analysis. A complete description of variable questions and coding can be found in the Supporting Information.

The main outcome variable was a dichotomic variable measuring the willingness to be vaccinated, represented by the question: "If a vaccine for COVID-19 becomes available, would you choose to get vaccinated?" (Yes = 1; No, Don't Know = 0). Starting from wave 12 (December 7−21, 2020), individuals who already received a vaccine were coded as "Yes."

Given the variability highlighted in the literature concerning the specific predictors correlated to vaccine acceptance, to develop more encompassing measures of perceived risk of COVID-19 and confidence, at the individual level we generated two standardized indexes constructed by saving individual predicted scores of a principal component analysis, with unrotated factors. The perceived risk index was constructed using three questions: "How dangerous do you think the COVID-19 risk is to your community?" "How likely is it that someone of the same age as you in your community becomes sick from COVID-19?" and "How serious would it be if you become infected with COVID-19?" The confidence index was constructed using four items in this question: "How much do you trust each of the following as information source on COVID-19?" Selected items investigated trust in four sources: local health workers, clinics, and community organizations; scientists, doctors, and health experts; the WHO; government health authorities and other officials. Indexes' Cronbach's α were, respectively, 0.61 and 0.68, both representing a unidimensional latent factor.

Individual-level controls included gender (male, female), age (18−30, 31−40, 41−50, 51−60, and over 60), educational level (low, medium, high), characteristics of the residential area (city, town and village, or rural area), perceived health status (poor, fair, good), and the self-reported level of exposure to COVID-19 information during the previous week (low, high).

To explore within-country changes, for each of the two indexes, we computed a weighted mean in each country wave from individual data. We subsequently aggregated country-wave values to compute country means, representing long-standing contextual elements. In this way, the country-level mean was insensitive to wave sample sizes, and each wave had the same relative weight in the analysis.

As an indicator of the pandemic activity, we used a variable from the "Our World in Data" data set: the officially reported daily number of new deaths per million inhabitants, for each day in each country. We recoded, using the average value between the previous and the subsequent day, nine negative occurrences with values ranging from −0.15 to −0.513, derived from official country corrections of historically inaccurate data. No updates were available for Vietnam from July 22 to 30, 2020, and we imputed these cells with the average value between the previous and subsequent values. We computed the average daily number of new deaths per million inhabitants for each country and country wave. In the latter, to better approximate respondents' exposition to a similar pandemic scenario, we included values of days in the first week of each wave and the week before the beginning of the wave. In this way, the values represented the average number of daily new deaths per million inhabitants with a 1-week lag. To consider the level and change of containment measures, we used the stringency index (Hale et al., 2021), considering eight indicators: school closing, workplace closing, canceled public events, restrictions on gatherings, limitations on public transport, stay-at-home requirements, restrictions on internal movements, and restrictions on international travel. We computed the mean stringency index for each country and country wave.

4 | METHODS

We began with a descriptive analysis, illustrating between- and within-country difference. Then, to assess the existence of cross-sectional and longitudinal associations, we elaborate set of bivariate linear probability models (LPMs) predicting the willingness to be vaccinated as a function of the perceived risk of COVID-19 or confidence. These descriptive models, although they could be greatly improved, cannot consider the complex structure of the data, where observations are nested in country waves and nested in countries, simultaneously control for compositional effects at the individual level, and fully exploit the longitudinal nature of observations. A solution proposed by Fairbrother (2014) is to treat data as nonrepeated

observations of a large random sample of microlevel units (individuals) nested in a data set with a panel structure, with multiple observations over time of the same countries. To do so, we used a revised version of a hybrid model for panel data analysis, applied to multilevel comparative longitudinal data that allows to

a. estimate the individual cross-sectional effects of an x on y,
b. decompose the within- and between-country effects of a time-varying country-level variable, and
c. control for individual-level compositional effects.

The basic model we adopted for this article was a random-intercept model structured as follows:

$$Y_{itj} = \beta_0 + \beta_1 X_{itj} + \beta_k X_{itj} + \gamma_{WE}\left(Z_{tj} - \bar{Z}_j\right) + \gamma_{BE}\bar{Z}_j + \sum_{t=1}^{T} \delta_t D_t + \upsilon_j + u_{tj} + e_{itj}.$$

This model has the usual multilevel longitudinal structure, where individuals (i) are nested in country-time (t), nested in countries (j) and where:

- Y_{itj} is the dependent dichotomic variable, assessing the willingness to be vaccinated;
- β_1 is a vector of coefficients identifying the individual-level association of risk perception or confidence on Y_{itj} across all waves and countries;
- β_k is a vector of control variables;
- γ_{WE} represents within-country effects of perceived risk and confidence. These coefficients are the result of the difference between the aggregated country-wave average of perceived risk and confidence, and the respective country-level mean. This coefficient captured the effect of a within-country change in perceived risk and confidence on a change in Y_{itj}.
- γ_{BE} are the between-country effects, the average country-level mean of perceived risk and confidence, capturing enduring cross-national differences.
- $\sum_{t=1}^{T} \delta_t D_t$ is a set of dummies to control for potential simultaneous but unrelated time trends in Z_{tj} and $\bar{Z}_j$. In other words, wave fixed effects guaranteed that within-country estimates were not biased because of a common time trend in the data.

Given that Z_{tj} and $\bar{Z}_j$ are orthogonal, the within-country coefficients do not suffer from omitted variable bias because of any time-constant country-level characteristics (Schmidt-Catran et al., 2019). They are identical to fixed-effects estimates of a balanced panel data. Nevertheless, they might be affected by time-varying heterogeneity. For this reason, in additional models, we included variables measuring the pandemic situation and the containment policies, disentangled in their within and between components. Finally, in the last model, we interacted the within-country pandemic situation with the within-country perceived risk index to assess whether the association between a change in perceived risk and a change in vaccine acceptance varies according to different levels of change in the pandemic activity.

Given the complexity of the model, we used an LPM and maximum likelihood estimation with robust standard errors and clustering observations at the country level. LPMs, besides allowing for a simpler interpretation and comparison of coefficients (Mood, 2010), avoid convergence problems that are frequent in complex multilevel models burdened by probability weights.

5 | RESULTS

We begin our analysis by describing between-country differences and the existence of variation over time in main predictors and outcome.

The top row of Figure 1 shows the weighted averages of vaccine acceptance, perceived risk, and confidence in each country, pooling all individual observations. The bottom row shows the change in weighted average levels, setting for each country an initial value of 0.

Given the high number of countries, we highlighted the trend of those countries that showed the highest and lowest average values in the top row. On average, slightly less than 65% [63.9%−66.2%] of survey respondents declared they would accept a vaccine once available, a percentage below the suggested threshold to reach herd immunity (Daly & Robinson, 2021; Sanche et al., 2020). Average vaccine acceptance had significant variability between countries, from Bangladesh, where over 84% [83.3%−85.3%] of respondents declared they would accept a vaccine, to France, where, across all waves, less than 46% [45.4%−46.6%] of respondents declared they would accept a COVID-19 vaccination. These results appear to be in line with previous findings on country levels of vaccine acceptance, where southern and eastern European regions performed poorly in terms of vaccine acceptance, way below countries in Southeast Asia and South America, with France consistently showing the lowest level of vaccine importance (Larson et al., 2016).

The graphs on the bottom row show there was significant variability over time, and that exploring between- and within-country relationships can point toward different scenarios. France, for example, presented a significant upward trend from wave 11 and on. Bangladesh, on the contrary, despite having the highest vaccine acceptance, saw this proportion constantly decrease over time, with a slight recovery only in the last three waves. A similar picture is depicted in the center panel. A country such as Poland, with the lowest average perceived risk, presented, over the course of almost 9 months, half an *SD* increase in the average perceived risk index, an increase stronger than any other observed country. Confidence seemed to exhibit, on average, a more limited variation over time. We will further test whether this variation over time is significant. These descriptive results suggest, we believe, the usefulness of investigating the relationship

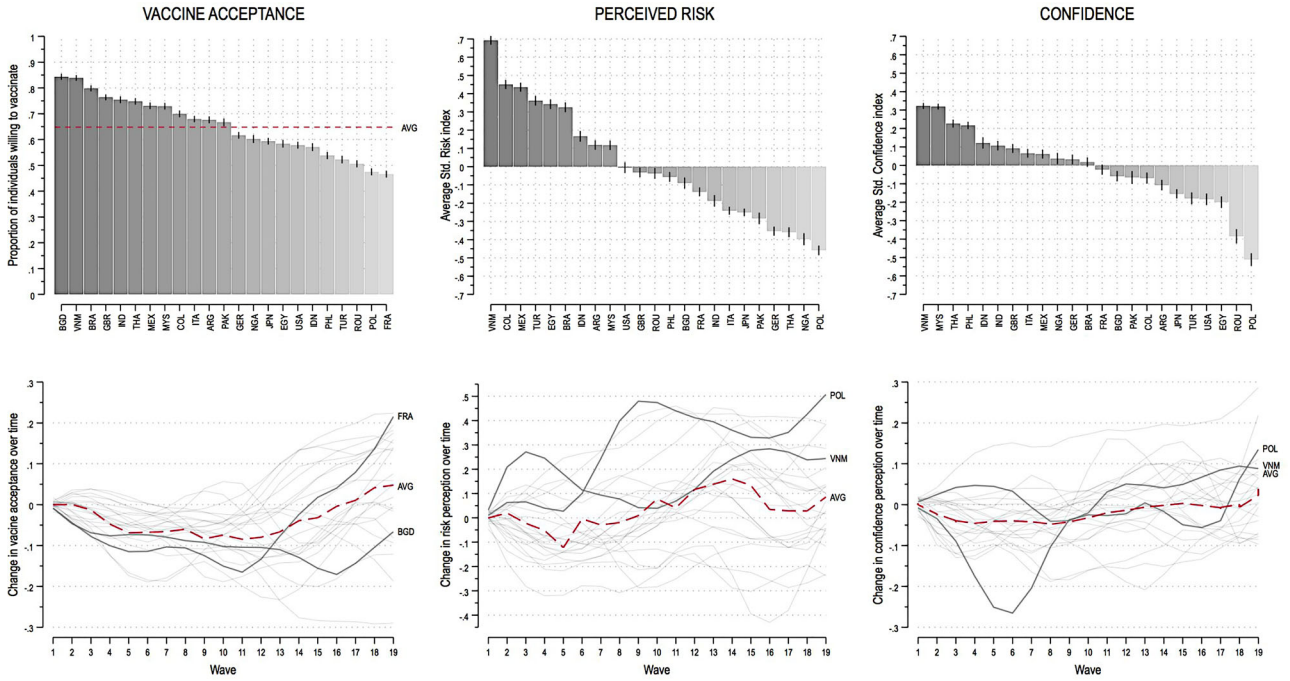

FIGURE 1 Between- and within-country differences.

Note: Top row graphs report average weighted vaccine acceptance, perceived risk, and confidence levels in each country with 95% CIs, sorted by levels magnitude. Bottom row graphs report weighted within-country change in vaccine acceptance, perceived risk, and confidence. Country lines and average country lines are set to an initial value of 0. Countries: ARG = Argentina; BGD = Bangladesh; BRA = Brazil; COL = Colombia; EGY = Egypt; FRA = France; GER = Germany; IND = India; IDN = Indonesia; ITA = Italy; JPN = Japan; MYS = Malaysia; Mex = Mexico; NGA = Nigeria; PAK = Pakistan; PHL = the Philippines; POU = Poland; ROU = Romania; THA = Thailand; TUR = Turkey; GBR = Great Britain; USA = United Stated of America; VNM = Vietnam.

between perceived risk and confidence from different angles, at both the cross-sectional and the longitudinal levels.

In Figure 2 we move, in fact, to investigating the bivariate relationship between willingness to be vaccinated, risk perception, and confidence at three different levels: between individuals, between countries, and within countries over time. Graphs in the left column plot the average marginal effect of perceived risk and confidence on the probability of accepting a COVID-19 vaccine in each of the 19 waves. These results were obtained from a bivariate LPM, pooling all observations, and interacting a wave-dummy with each index. The two graphs show a significant positive association between individual levels of perceived risk, confidence, and willingness to be vaccinated, respectively. Whereas the former seemed to be somewhat stationary over time, the latter has an upward trend, suggesting a strengthening of the relationship between confidence and vaccination. These results are in line with most of the existing literature on vaccine acceptance and with more recent investigations of the COVID-19 pandemic.

In the center panels, we explored the between-county relationships using a bivariate ordinary least squares (OLS) model, regressing the average country-level perceived risk and confidence on the average willingness to be vaccinated. Visually, slopes of the linear regression lines are positive, indicating that between-country differences in levels of perceived risk and confidence are associated with different average levels of vaccine acceptance. The association appears to be stronger in the bottom graph. This result, obtained by pooling 19 waves, suggests the existence of persistent differences between countries over the course of the pandemic. In the last part of the analysis, we test whether these differences are significant when controlling for possible confounders.

Finally, in the right column panels, we assess whether there were longitudinal relationships that would justify investigating the covariation over time in each country. We pooled all country waves and, in a bivariate OLS model, regressed the de-meaned perceived risk and de-meaned confidence indexes on the de-meaned vaccine acceptance proportion. The graph represents therefore the association between a change in x on a change in y. In both cases, there appears to be a positive association over time, although especially for the bottom-right graph, the β coefficient seems to be significantly smaller than the one for between-country differences.

This descriptive analysis, suggesting the existence of positive relationships at different levels of analysis, calls for a more precise investigation. We do this through a series of multilevel longitudinal random intercept models, simultaneously estimating cross-sectional and longitudinal associations, controlling for compositional effects and for possible unrelated time trends in the data. Table 1 reports the results of the multilevel analysis.

Model 0 is an empty model with no covariates other than the constant term. It substantially reproduces the results of the top left panel of Figure 1, taking into account the structure of

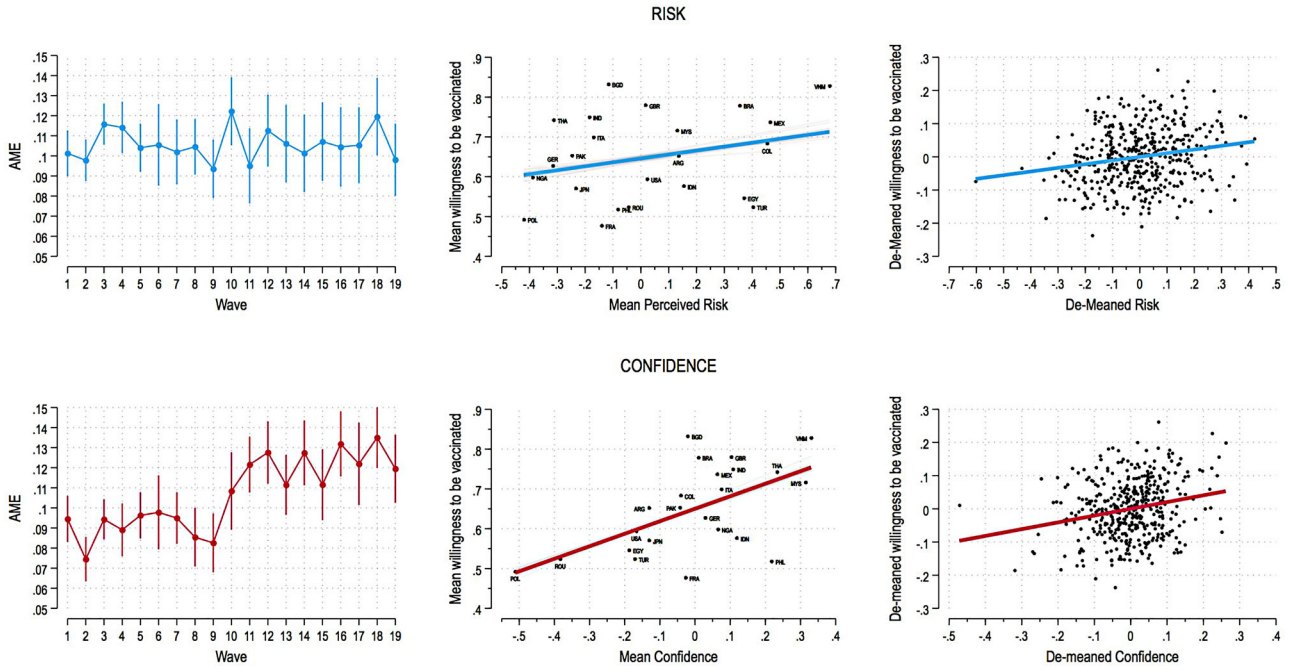

FIGURE 2 Bivariate associations at individual level, country level, and within countries over time.

Note: Graphs in the left column report the average marginal effects of linear probability models pooling individual-level observations (n = 142,264) and interacting a wave dummy with (i) the perceived risk index (top row graph) and (ii) the confidence index (bottom row graph) on vaccine acceptance. Graphs in the center column report the association between (i) perceived risk and vaccine acceptance weighted means at country level (top row), (ii) confidence and vaccine acceptance weighted means at country level (bottom row), and (iii) the fitted OLS lines pooling country-level observations (n = 23). Graphs in the right column report the relationship between (i) the de-meaned weighted country waves' average levels of risk perception and vaccine acceptance (top row), (ii) the de-meaned weighted country waves' average levels of confidence and vaccine acceptance (bottom row), and (iii) the fitted OLS lines pooling country wave observations (n = 437).

the data. The grand mean is the average willingness to be vaccinated across all individuals. The variance at the individual level was 0.211; at the country-wave level, it was 0.0064, and at the country level, it was 0.0112. The intraclass correlation (Hox, 2010, p. 34, eqs. 2.18−2.19) at the country level was 0.049, and at the country-wave level, it was 0.028. Overall, about 8% of the variance was not located at the individual level. Z-test scores indicated that variance was significant at each of the three levels ($p < 0.001$). This suggested there was significant variability at the country and country-wave levels that can be explained.

In model 1, we added individual-level variables. Individual characteristics reduced the variance components at the country level by 21% and at the country-wave level by 5%. Compositional effects can, therefore, explain only a limited fraction of the variance at the two higher levels. This leaves the variance at the country and country-wave levels substantially unexplained. In model 2, we included wave-fixed effects. Compared to the null model, the explained variance at the country-wave level was reduced by 30%, suggesting the existence of unrelated time trends in the data and the usefulness of including time-fixed effects.

In model 2, the coefficients of perceived risk and confidence were both positive; a standard deviation increase was correlated, respectively, to increases of 8.4% and 7.3% in the probability of accepting a vaccination. Also considering the diverse set of countries and time points analyzed, this result suggests a positive answer to our first research question, providing further support to recent results that stressed the importance of the relationships between levels of perceived risk, confidence, and vaccine acceptance. For a more fine-grained perspective, a table disaggregating each measure or perceived risk and confidence is available in the Supporting Information.

Females and individuals above 30 years old were less likely to be willing to be vaccinated. On the contrary, more educated individuals were, on average, more willing to be vaccinated. While we do not find significant differences between individuals' health status or residential area, we do find that higher exposure to information is correlated with higher levels of vaccine acceptance.

In model 3, we introduced the main predictors at the country-wave and the country levels, decomposing the between-country association (BE) from the one within-country association over time (WE). Model fit significantly improved after introducing these two indexes, as indicated by Akaike information criterion (AIC) and Bayesian information criterion (BIC) measures. We do not find a significant between-country association among average levels of perceived risk and willingness to be vaccinated. We do find, on the contrary, a significant relationship between countries' average level of confidence and willingness to be vaccinated. We, therefore, found only a partial positive answer to our second research question, investigating the existence of an association between long-standing contextual differences in the relationship between perceived risk, confidence, and

TABLE 1 Multilevel longitudinal models.

	Null b/(SE)	M1 b/(SE)	M2 b/(SE)	M3 b/(SE)	M4 b/(SE)	M5 b/(SE)
Individual-level variables						
Gender (ref. = male)						
Female		−0.085***	−0.085***	−0.085***	−0.085***	−0.085***
		(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Age (ref. = 18–30)						
31—40		−0.032***	−0.032***	−0.032***	−0.032***	−0.032***
		(0.008)	(0.008)	(0.008)	(0.008)	(0.008)
41—50		−0.034***	−0.034***	−0.034***	−0.034***	−0.034***
		(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
51—60		−0.019*	−0.019*	−0.019*	−0.019*	−0.019*
		(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Over 60		0.023	0.023	0.023	0.023	0.023
		(0.018)	(0.018)	(0.018)	(0.018)	(0.018)
Educational level (ref. = lower edu)						
Mid-educated		0.007	0.007	0.007	0.007	0.007
		(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Higher educated		0.041***	0.041***	0.041***	0.041***	0.041***
		(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Area (ref. = city)						
Town		−0.005	−0.005	−0.005	−0.006	−0.005
		(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Village or rural area		−0.010	−0.010	−0.010	−0.010	−0.010
		(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Self-reported health status (ref. = poor)						
Fair		0.007	0.007	0.007	0.006	0.006
		(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Good		−0.002	−0.002	−0.002	−0.002	−0.002
		(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Information exposure (ref. = low)						
High		0.039***	0.039***	0.039***	0.039***	0.039***
		(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Perceived risk index		0.084***	0.085***	0.085***	0.085***	0.085***
		(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Confidence index		0.073***	0.073***	0.073***	0.073***	0.073***
		(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
Country and country-wave–level variables						
Perceived risk [WE]				0.015	−0.054	−0.054
				(0.033)	(0.033)	(0.033)
Perceived risk [BE]				−0.016	−0.051	−0.053
				(0.047)	(0.053)	(0.054)
Confidence [WE]				0.053	0.056	0.059
				(0.050)	(0.043)	(0.043)
Confidence [BE]				0.222**	0.226*	0.228*
				(0.072)	(0.093)	(0.093)

(Continues)

TABLE 1 (Continued)

	Null b/(SE)	M1 b/(SE)	M2 b/(SE)	M3 b/(SE)	M4 b/(SE)	M5 b/(SE)
New deaths per mill. [WE]					0.010***	0.010***
					(0.003)	(0.003)
New deaths per mill. [BE]					0.003	0.003
					(0.013)	(0.013)
Stringency index [WE]					0.001	0.001
					(0.001)	(0.001)
Stringency index [BE]					0.003	0.003
					(0.003)	(0.003)
New deaths per mill. [WE] × Perceived risk [WE]						−0.010
						(0.008)
Constant	0.649***	0.653***	0.689***	0.690***	0.490**	0.492**
	(0.023)	(0.022)	(0.023)	(0.023)	(0.173)	(0.173)
			+ Wave FEs	+ Wave FEs	+ Wave FEs	+ Wave FEs
Variance components						
Country	0.0112	0.00881	0.00891	0.00705	0.00615	0.00621
Country wave	0.00641	0.00609	0.00447	0.00445	0.00380	0.00379
Individual	0.211	0.193	0.193	0.193	0.193	0.193
Log likelihood	−91724.599	−85526.665	−85472.253	−85468.422	−85441.050	−85440.526
AIC	183457	171089	171016	171017	170970	170971
BIC	183497	171267	171372	171412	171404	171415

Note: All models are random intercept models, estimated using a linear probability model (LPM). SE clustered at country level. Weighted coefficients. [WE] = within; [BE] = between. $N = 142.264$. Robust standard errors in parentheses.
Abbreviations: AIC, Akaike information criterion; BIC, Bayesian information criterion.s
***$p < 0.001$, **$p < 0.01$, *$p < 0.05$, two-tailed.

vaccine acceptance. This appears to be valid for confidence levels, but not for perceived risk.

The third research question aimed at verifying a possible within-country association over time, where a change in perceived risk and confidence might have been associated with a change in willingness to be vaccinated. After controlling for compositional effects and time trends, and decomposing between and within associations, our results did not show any significant relationship between perceived risk, confidence, and willingness to be vaccinated within countries over time. It should be noticed that, in the random part of the model, there was no decrease in country-wave variance. This suggests that within-country change in vaccine acceptance might not be correlated with within-country changes in perceived risk and confidence.

As we underlined in the methodology section, within-country associations are sensitive to time-varying heterogeneity. For this reason, in model 4, we introduced a variables measuring the pandemic status, the officially reported new number of deaths per million inhabitants, and the stringency index. We found a significant association for the within-country change in the number of new deaths per million inhabitants. An increase of one additional death per million inhabitants was correlated with a 1% increase in the willingness to be vaccinated. Our model suggested that this relationship is not based on a change in perceived risk and confidence. Rather, it is connected to unexplained unobserved within-country heterogeneity.

Finally, in the last model (M5) we tested Research Question 4, asking whether a within-country association of perceived risk with the willingness to be vaccinated could vary according to a change in the pandemic activity. We tested this research question by interacting the within-country change in perceived risk with the within-country change in the pandemic activity while controlling for the changes and levels of containment policies. We did not detect a significant association. Our model suggested that the association between a change in perceived risk and a change in willingness to be vaccinated does not vary according to different within-country changes in the pandemic status. Furthermore, introducing the interaction term caused the model fit to worsen, suggesting that introducing the interaction term was unwarranted.

6 | DISCUSSION

In this article, we investigated the relationship between risk perceptions, confidence, and willingness to accept a vaccine against COVID-19. In the last decade, numerous studies have

addressed the primary role of individuals' perceptions in vaccine acceptance, an effort that accelerated greatly after the COVID-19 pandemic erupted. We argued that one main issue of prior studies was that they relied on one point in time cross-sectional studies. This limit is almost unavoidable, given the sudden nature of a pandemic. We further maintained that to develop effective policy-oriented interventions to sustain vaccine acceptance, it might be of primary importance to look at the association between changes in perceived risk and confidence and changes in the willingness to be vaccinated. Our results further illuminated the complexity of vaccine acceptance, suggesting the existence of different relationships at each level of analysis.

In the first part of the analysis, descriptive results indicated significant between-country variability in the proportion of individuals willing to be vaccinated and in the average levels of perceived risk and confidence. This result was in line with previous prepandemic studies. It showed how differences between countries might persist and how they might affect the acceptance of a vaccine for COVID-19. At the same time, we showed that over the course of the 19 waves observed in this study, there was significant variation within each country.

For this reason, we explored the existence of an association between individual perceptions and vaccine acceptance at both individual and country levels, both cross-sectionally and longitudinally. We found, in the initial exploratory analysis, a positive relationship in all three cases, although the within-country longitudinal relationship appeared to be weaker than the between-country one.

To assess the existence and magnitude of these associations more precisely, we used a series of multilevel longitudinal random intercept models (Fairbrother, 2014). The aim was to disentangle the relationships between three levels of analysis, controlling for individual compositional effects and unrelated time trends. We found that higher individual levels of perceived risk and confidence were correlated with higher levels of vaccine acceptance. This result was consistent with the most recent research (Attema et al., 2021; Freeman et al., 2020; Karlsson et al., 2021) and with previous research on vaccine acceptance in pandemic scenarios (Gidengil et al., 2012; Vinck et al., 2019). By using a large-scale survey with a diverse sample of countries and a large time-span (at least, relative to the pandemic activity), results further supported these findings. Although recent research has shown some variability in the strength and specificity of this relationship (Faasse & Newby, 2020; Karlsson et al., 2021), we argued that one reason behind this variability might be correlated to the difficulty of conceptualizing and measuring individual perceptions. For example, we stressed that there is no consensus on the concept of confidence (see, e.g., Larson et al., 2015; MacDonald, 2015; Verger & Dubé, 2020) or that risk perception might be disentangled in various components, each with specific characteristics (Brewer et al., 2017; Weinstein et al., 2007). Furthermore, many recent contributions insisted on very different contexts, and their results might be connected to underlying unobserved contextual determinants. Further studies might be directed toward developing a clearer, shared definition of concepts and measurement models, to increase the comparability of research. On the other hand, our analysis suggested that these individual-level associations appeared to be stable across contexts and time. The individual-level analysis also revealed the important associations between sociodemographic characteristics and vaccine acceptance, with a particular reference to the role of educational level. Although there exist mixed results in the pre-COVID-19 literature (Dubé et al., 2013; Kirkland, 2012), our findings suggested that, on average, a high educational level was a protective factor against vaccine hesitancy. This result is in line with most recent published literature on the COVID-19 case (see, e.g., Lazarus et al., 2021; Phillips et al., 2022; Robertson et al., 2021), especially if using large-scale, cross-country samples.

We did not find a significant correlation between a change in perceived risk and confidence and a change in vaccine acceptance within countries over time. Previous longitudinal investigations (Bangerter et al., 2012; Gidengil et al., 2012; Vinck et al., 2019) showed how risk, confidence, and vaccine acceptance might not have followed the same trend, and our analytical strategy tested this covariation more robustly. We believe this result, different from those at the individual level, is not contradictory. Rather, this further illuminates the complexity of the relationship between perceived risk, confidence, and vaccine hesitancy, and it illustrates the importance of disentangling associations between levels and change. Substantively, it suggests that, while increasing people's awareness about COVID-19 characteristics and fostering individuals' confidence can be a relevant strategy to promote individuals' vaccine acceptance, these predictors might not be the most relevant when seeking to increase countries' average vaccination rates. Indeed, recent longitudinal studies showed that vaccination intentions tend to be stable over time and might be rather hard to change (Chambon et al., 2022). While refraining from offering specific policy suggestions, as proposed by IJzerman et al. (2020), our results suggest instead the importance of developing additional research in this field, especially focused on highlighting the different findings between cross-sectional, individual-level associations, and country-level change over time. Implementation science (Nilsen & Birken, 2020) is devoted to the specific task of finding the right policy tools that are evidence based in the context of public policy design.

Last, we found a significant association between country levels of confidence and vaccine acceptance. This association, computed using a time span of over 9 months, could represent persisting differences between countries. Vaccine hesitancy research showed multiple times that contextual factors are elements of primary importance in influencing vaccine uptake and willingness to vaccinate and that prepandemic contextual conditions might also affect COVID-19 vaccine acceptance. The efficacy of vaccination programs might have had the unintended consequence of generating a lack of concerns about vaccine preventable diseases, undermining vaccine acceptance in those high-income countries that more than

others have seen vaccination's beneficial effects (Fridman et al., 2021; Kahn & Luce, 2006; Larson et al., 2012). Empirical studies also suggest that the availability of internet access is correlated to higher vaccine skepticism because of the greater possibility of misinformation spread (Lunz Trujillo & Motta, 2021), a problem that disproportionally affects high-income countries. On the same line, unsubstantiated context-specific vaccine scares greatly impacted vaccine acceptance for many years (Brewer et al., 2017; Dubé et al., 2015) and potentially contributed to context-specific COVID-19 vaccine skepticism. Additionally, the vaccine controversy has been used several times in different contexts as a tool for political gain, fostering vaccine skepticism in specific demographic and political subgroups in the population (Lunz Trujillo & Motta, 2021). Finally, research has shown several times that vaccine acceptance is socially stratified. That is, significant subgroups in the population are systematically less likely to accept vaccination. These include less educated individuals (Dryhurst et al., 2020) and ethnic and racial minorities (Dryhurst et al., 2020; Robertson et al., 2021), unequally distributed between contexts. These examples show that contextual, social, and historical motives are factors of primary importance in coping mechanisms involving an unprecedented and clearly disruptive event such as a global pandemic.

This work has some limitations that must be addressed. First, the sampling method suggested that point estimates should be considered carefully, since a selection of countries based on the availability of a sufficient pool of social media, limits the external validity of results. For the same reason, a bias is naturally induced by excluding individuals that do not have a social media account. Finally, Collis et al. (2022) show that conversion rates—expressing how many users clicked on the surveys versus how many saw the survey prompt on the Facebook page—vary greatly between contexts, reflecting unobserved contextual elements, such as the perceived or actual cost of data in each country. On the other hand, nonresponse modeling and poststratification weights were developed to minimize the representation error due to coverage, sample variability, and nonresponse bias, substantially limiting the impact of such potential biases (Collis et al., 2022). Additionally, the diversity of counties surveyed, the sample size, and the wide range of time points allowed us to gain valuable insights that, to the best knowledge of the authors, are still underdeveloped in the literature. Second, our main indexes cannot capture the wide range of components of perceived risk and confidence as depicted in the literature. The availability of more refined dimensions could increase the ability to capture all the faceted dimensions of these concepts. Third, the variable we used as a proxy for change in the pandemic status is likely to underestimate the real number of COVID-19 casualties. Furthermore, this issue is likely to be unevenly distributed across the analyzed counties. Unfortunately, for the time being, and to the best knowledge of the authors, there appears not to exist an equally time-sensitive, comparable, and publicly available indicator for such a large number of countries. Finally, between-country associations were computed on a very limited number of cases as for every country-level estimate. This strongly limits the possibility of controlling for confounders, and it always leaves open the possibility that significant between-country associations are due to unobserved heterogeneity.

7 | CONCLUSION

In this article, we investigated the issue of COVID-19 vaccine acceptance, and of the relationship between perceived risk, confidence, and willingness to accept a vaccination. In the introductory section, we underlined that vaccine acceptance is a complex decision that stems from the interplay of individual, social, cultural, political, and historical factors (Dubé & MacDonald, 2020; Dubé et al., 2021). At the same time, we evidenced that a relevant part of recent research exploits one-country, one point in time data. While this strategy is extremely useful for obtaining time-sensitive data and analysis in a pandemic scenario, it might impede the observations of relevant associations emerging over time and limits the generalizability of results across contexts. In this article, we relayed on large-scale comparative longitudinal data investigating 23 countries over the span of 9 months and proposed a series of multilevel longitudinal models to assess the relationship between perceived risk, confidence, and willingness to vaccinate at three different levels: at the individual level, between countries, and within countries over time.

Results showed that respondents' levels of risk perception and confidence were positively correlated to the willingness to accept a vaccination's levels. This result aligns with most of the recent literature highlighting the centrality of these construct for individuals' vaccine acceptance (see, e.g., Brewer et al., 2017; Larson et al., 2015). At the same time, we do not find a significant relationship within countries over time. This suggests that generating an increase of vaccination rates within countries, hence inducing a change, could be correlated to different mechanisms. Results are therefore a starting point to stimulate further research using longitudinal data in this field. Finally, we find a positive relationship at the country level between levels of confidence and willingness to vaccinate, highlighting, in agreement with most recent research (Dubé et al., 2021), the relevance of long-standing contextual characteristics for vaccine acceptance.

The contributions of this article are threefold. First, we addressed a gap in the empirical literature concerning the role of risk and confidence in vaccine hesitancy that frequently uses one point in time cross-sectional data. Indeed, we showed that, in the analysis of a complicated issue such as vaccine acceptance in a pandemic scenario, disentangling relationships at diverse levels of analysis can produce significantly different results.

Second, our results suggested that fostering the COVID-19 vaccine might require different and simultaneous strategies. To increase individual acceptance, it might be important to increase awareness of COVID-19 characteristics and promote trust in a diverse set of actors. However, at the country level,

fostering a change in vaccination rates might be correlated to dimensions other than perceived risk and confidence. Harrison and Wu (2020) suggested, for example, that increasing public acceptance of vaccines might require a reimagination of the culture of public health that focuses more on the social, contextual, and moral enhancements that vaccines might bring to the entire community. Further research is needed to describe such mechanisms in order to develop relevant policy suggestions fostering the acceptance of vaccinations.

Third, our analysis showed that there are long-standing contextual effects involving vaccine confidence. Indeed, fostering vaccine acceptance might be a long-term commitment, and addressing differences and inequalities deeply rooted in our societies might prove to be important for vaccine acceptance as well.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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