Trust in science, social consensus, and vaccine confidence

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Abstract

While scholarly attention to date has focused almost entirely on individual level drivers of vaccine confidence, we show that macro-level factors play an important role in understanding individual propensity to be confident about vaccination. We analyse data from the 2018 Wellcome Global monitor survey covering over 120,000 respondents in 126 countries to assess how societal level trust in science is related to vaccine confidence. In countries with a high aggregate level of trust in science, people are more likely to be confident about vaccination, over and above their individual level scientific trust. Additionally, we show that societal consensus around trust in science moderates these individual and country level relationships. In countries with a high level of consensus regarding the trustworthiness of science and scientists, the positive correlation between trust in science and vaccine confidence is stronger than it is in comparable countries where the level of social consensus is weaker.

Introduction

While there is much that we still do not understand about the novel coronavirus, on one central issue there is near universal consensus – the world will not return to anything approaching normal life until an effective and comprehensive global programme of vaccination has been successfully implemented. An intense international effort is now underway to deliver this key objective, with nine vaccines having received regulatory approval at the time of writing and vaccination programmes being rolled out in many countries across the world[i]. But even though this herculean endeavour has been delivered over a time-scale unprecedented in the history of vaccine development, it will not on its own be sufficient to free the world from the grip of the pandemic. For, unlike other medicines, vaccines must work at *both* the individual and the societal levels to be effective at eliminating viral infections – without achieving high rates of population immunisation, the virus is likely to remain endemic[ii]. While the exact threshold is not yet known, it seems that it will be necessary for countries to achieve a vaccination rate of over 70% to attain 'herd immunity' against the coronavirus[iii].

Worryingly in this regard, survey evidence suggests that substantial minorities in many countries may refuse to be inoculated against covid-19[iv]. A cross national survey carried out in May 2020 by Kantar found, for example, that 19% of the US public said they would probably or definitely not get vaccinated, with corresponding figures of 14%, 23%, and 24% in the UK, Germany, and France, respectively[v]. More recently, a survey by Imperial College London in November 2020 found only minorities of the public reporting they would definitely get vaccinated against covid-19 in Canada, Germany, Japan, Singapore, and France[vi]. While hypothetical survey questions are often a poor guide to future behaviour, in the case of vaccination there are good reasons to assume that these figures may represent broadly accurate estimates of rates of vaccine refusal. This is because, despite their unrivalled success in limiting the spread of viral infections around the world[vii], there is a long history of public scepticism about and resistance to mass inoculation programmes[viii].

If the global challenge of widespread immunisation against the coronavirus is to succeed, it is crucial that we better understand the social, economic, and psychological factors that encourage or inhibit vaccine uptake. Our objective in this article is to contribute to this pressing endeavour by assessing the role of societal level trust in science in fostering public confidence in vaccination programmes. To date, scholarly attention has focused almost entirely on individual level trust in science and medical professionals within single country contexts, with a wealth of evidence showing that trust in science serves as a key psychological factor underpinning vaccine acceptance[ix].

Our primary interest here, though, is on how societal-level scientific trust is associated with vaccination uptake – is the average level of trust in science in a country positively related to vaccine confidence, over and above the individual level relationship? It is common in hierarchically structured social systems for a variable to have additional complementary or even divergent effects at the individual and macro levels[x]. For example, in the United States richer voters generally support the Republican Party within states, while wealthier states tend to

lean Democrat[xi]. The importance of considering the possibility of macro-level influences in addition to individual level relationships has also been demonstrated for attitudinal variables, with Fairbrother (2016)[xii], for instance, finding a strong positive association between country level political trust and support for environmental protection policies, net of the positive contribution of individual level political trust.

In addition to considering how country-level differences in average levels of trust in science are related to vaccine confidence, an important contribution of our paper is to assess the role of societal consensus about the trustworthiness of science and scientists, operationalized as the *variability* in trust assessments around the national averages. There are good reasons to believe that the level of societal consensus in trust assessments may differ quite substantially across locales[xiii] and that such differences may be consequential for individual and societal responses to the perception and assessment of risks[xiv]. Recent work in criminology, for example, has shown that the extent of public consensus on the level of collective efficacy in local neighbourhoods plays an important role in moderating how individual assessments of neighbourhood characteristics affect perceptions of crime risk[xv]. People look to the attitudes and behaviours of others to determine what is normal, beneficial and accepted, and when the normative principle about the positive or negative value of an agent or institution such as scientists and science is widely held, there will be a stronger social influence on individual assessments of what is and is not socially acceptable or appropriate[xvi].

How, then, does trust in science affect vaccine acceptance? In its modern incarnation, epidemiologists refer to scepticism about the safety and health benefits of vaccination as 'vaccine hesitancy',[xvii] defined as "[a] delay in acceptance or refusal of vaccines despite availability of vaccine services"[xviii]. According to the WHO's "3 Cs" model, the propensity to be vaccine hesitant is a function of three factors: complacency, convenience, and confidence[xix]. Complacency results, in an unfortunate irony, from the success of vaccination programmes in eliminating viral epidemics which, in turn, leads individuals to discount the risk of infection and the need for protection through inoculation. Convenience relates to practical and logistical barriers to accessing vaccines such as cost, location, availability of transport links, and the quality of facilities which, collectively or in isolation, influence hesitancy to be vaccinated.

The vaccine confidence component of this triumvirate, which is our focus here, is the extent to which people believe that vaccines are safe, effective and consistent with their religious beliefs[xx]. Vaccine confidence derives from the trust that individuals have in the systems, institutions, and actors that produce and deliver immunisation programmes[xxi]. This includes trust in the legitimacy of the political institutions that propose and provide the legal and regulatory frameworks for mass vaccination, in the healthcare systems and workers that deliver vaccines on the ground, and in the science that underpins vaccine efficacy and safety[xxii]. As in other contexts where science and technology intersect with daily lives, most citizens do not have the time, expertise, or inclination to assess for themselves the risks and hazards arising from mass inoculation programmes. For this reason, trust in the technical competence and social responsibility of scientific experts is a crucial, if implicit, underpinning for citizen

and societal decision making on vaccination. Trust in science and scientists serves, then, as an efficient heuristic shortcut to determining an appropriate judgement about the safety, effectiveness, and importance of vaccination that would otherwise require costly and error prone cognitive processing for individuals[xxiii xxiv xxv].

This then accounts for how individual level assessments of the trustworthiness of science are related to vaccine confidence. But how does trust in science at the societal level shape individual confidence in vaccination programmes? The proposed mechanism here is not that people have a conscious or explicit mental representation of the level and variability of trust amongst their fellow citizens, albeit that this may be true for some people. Rather, they acquire informal impressions of how science is valued or contested through local social interactions, media representations, and cultural and political debate and these factors combine to shape individual assessments of the trustworthiness of science[xxvi xxvii]. It is well known that trust is facilitated in trusting environments[xxviii xxix]. In short, instead of costly information processing, people rely on heuristics about the trustworthiness of science and this tendency is likely to be more pronounced when there is a strong societal consensus about the value, utility, and safety of science and technology.

This is because the same social pressures that lead individual to converge toward the normative consensus in society on science is likely also to encourage people to conform to widely shared beliefs about the benefits and risks of vaccination. In a country where there is a strong social consensus that science can be trusted, we therefore expect vaccination confidence to be high. Conversely, in a country where there is a social consensus that science and scientists are not trustworthy, we expect vaccination confidence to be low. What applies at the macro-level, we also expect to manifest for individual level trust, i.e. people's assessments of the trustworthiness of scientists will have a stronger positive association with vaccine confidence in countries with a high level of social consensus that trust in science is the normatively appropriate assessment to make of these actors.

Results

As described in the Methodology section, our analysis comprises three steps. First, we derive a measure of trust in science using an IRT model fitted to seven items tapping different aspects of trust in science. Second, we fit 'location-scale' models predicting between-individual and between-country heterogeneity in the mean and standard deviation of trust in science, controlling for individual and country level characteristics. Third, we take the country specific residuals for the mean and standard deviation of trust from this first stage model and include them as predictors in a multilevel model, where the outcome is individual-level vaccine confidence. In this final model, we assess the individual and country level associations between trust in science and vaccine confidence including their *interactions* with the level of societal consensus. Before reporting the results of these models, we briefly describe how our measure of trust in science is distributed across countries in the Wellcome Global Monitor.

As has been reported elsewhere[xxx], the Wellcome Global Monitor reveals a high level of trust in science globally, with more than four fifths of people around the world reporting 'some' or 'a lot' of trust in science, and similar numbers reporting this level of trust in scientists (85%) and their ability to find out accurate information about the world (85%). Note that for global estimates we apply a weight to account for differences in population size between countries. These global averages are underpinned by considerable heterogeneity, with countries accounting for 12% of the total variance in individual-level scientific trust. Trust in science is highest in North America, Western Europe, and Australasia and lowest in South America, Eastern Europe, and Africa. Vaccine confidence is even higher than trust in science, with 93% of people globally agreeing that vaccines are important for children to have, 81% that vaccines are safe, and 86% that vaccines are effective. Vaccine confidence also varies considerably across countries, with 14% of the total variation in confidence between individuals attributable to between country differences. The highest levels of vaccine confidence are found in Africa and parts of Asia and the lowest levels in Eastern Europe.

The results of the 'location-scale' models are presented in Table 1. The top part of the table presents the results from the location (mean) equation, showing how mean levels of trust in science differ across the individual and country covariates. Trust in science is higher in wealthier countries and in countries where income inequality is lower. Men, people with more education, and people with higher incomes also report more trust in science. The bottom part of table 1 shows the results from the scale (standard deviation) equation, with positive values indicating a higher within-country standard deviation and negative values a lower within-country standard deviation. The social consensus on trust science is substantially stronger (i.e. the within-country standard deviation is lower) in countries with higher levels of formal education and with lower levels of income inequality. Within countries, social consensus around trust in science is greater amongst more educated people and those with higher incomes. Having conditioned on these country and individual covariates, countries still vary substantially in levels of consensus, with a scale residual of 0.114. This variability is largely unrelated to a country's mean level of trust in science, with a correlation of 0.140 between the mean and scale residuals.

INSERT TABLE 1 HERE

Figure 1 shows the estimated within-country standard deviations for trust in science, summarising the extent to which social consensus around trust in science varies across countries (the spread of the country standard deviations is captured by the scale residual of 0.114). On average, the standard deviation of trust in science across countries is 0.83 (indicated by the horizontal red dotted line), ranging from a minimum of 0.61 to a maximum of 1.22, with many of the between country differences significant at the 95% level of confidence. Note that higher scores in Figure 1 indicate more within-country variability and, therefore, a *weaker* social consensus of trust in science. The Czech Republic has the lowest social consensus on trust, with Guinea, Romania, Botswana and the United Arab Emirates also showing notably low levels of agreement about whether science can be trusted. At the other end of the spectrum, Thailand, Latvia, Togo, Iran, Nepal, Italy, and Japan are the

countries with the highest national consensus on trust in science. There is no obvious regional, political, religious, or economic pattern to these country groupings.

INSERT FIGURE 1 HERE

Turning now to the second step model, we test for a moderating relationship between social consensus and the mean level of trust in science by including the residuals from the first stage model as predictors of support for vaccination, with their main effects interacted with the strength of social consensus (the scale equation residual). The parameter estimates are presented in Table 2 for the combined responses to the vaccine convfidence items and for each of the three items separately. For each outcome, model 1 includes the country and individual level main effects of trust in science and model 2 adds their interactions with the strength of societal consensus on trust in science. For the overall vaccine support measure, people who are more trusting of science and scientists are also more vaccine confident ($z=54.3$, $df=1$, $p<0.001$, two-tailed, logit=0.489, confidence interval=0.472-0.507).

Even controlling for this individual level relationship, people in countries with higher average levels of trust in science are also more confident about vaccination ($z=2.99$, $df=1$, $p=0.004$, two-tailed, logit=0.895, confidence interval=0.301-1.481). We therefore find support for a positive macro-level relationship between public trust in science and how confident individuals are about vaccination. Model 2 shows that these individual and macro-level relationships are moderated by the strength of societal consensus around trust in science – at higher levels of public consensus that science is trustworthy, the strength of the association between trust and confidence is greater for both individual and country level trust in science. The same patterns are also evident for the each of the three vaccine confidence items considered separately.

INSERT TABLE 2 HERE

These interactions are easier to process visually. Figure 2 (top panel) plots fitted values from model 2a in Table 2 by the country level average trust in science (x axis) and vaccine confidence (y axis). Figure 2 reveals a substantial difference in the strength of the association between country level trust in science and vaccine confidence; the average level of trust in science is only positively related to vaccine confidence when the social consensus on trust in science is strong (left hand panels). In countries where disagreement about trust in science is more prevalent (right hand panels), the average level of trust in science is not significantly associated with vaccine confidence. The same moderating relationship is also evident for individual-level trust within countries (Figure 2, lower panel). This 'cross-level' interaction shows that the association between individual trust in science and vaccine confidence is stronger when there is more societal agreement that science and scientists can be trusted, although the substantive magnitude of this interaction is considerably weaker compared to what is evident at the macro-level.

INSERT FIGURE 2 HERE

Discussion

As the world waits impatiently for vaccines to quell the coronavirus pandemic, attention is intensely focused on the speed and efficiency of the nascent inoculation programmes being rolled out in countries across the world. However, it is well known that in order for vaccines to be effective in controlling and eliminating viruses, they must not only protect individuals from infection, they must also be taken by a sufficiently large proportion of the population to attain 'herd immunity'[xxxi]. Worryingly in this regard, recent surveys have revealed substantial minorities in many countries who say they are unlikely to be vaccinated, even when a safe and effective vaccine is available – an example of what epidemiologists refer to as 'vaccine hesitancy'[xxxii]. Given the crucial importance of achieving high rates of vaccination against coronavirus across the world, not just in countries that can afford the vaccine and have the infrastructure to administer quickly at scale, it is essential that we better understand the individual and societal sources of vaccine hesitancy.

In this article, we have focused on the macro-level association between trust in science and vaccine confidence, a key component of vaccine hesitancy. Using representative survey data covering 126 countries, we have shown that both the average level of trust in science in a country and the variability around that average are important in understanding individual level vaccine confidence. Our results suggest that, as with the protective effects of vaccines, public confidence in immunisation programmes is shaped by factors operating at the community as well as the individual level.

The Wellcome Global Monitor data was, it should be acknowledged, collected before the start of the covid-19 pandemic, so we must be cautious about extrapolating these findings to the current extraordinary context. Nonetheless, while a replication of these analyses on data collected during the pandemic would clearly be of value, there is no strong reason to assume that our core findings should not also be evident in the specific case of coronavirus vaccination. Our findings and conclusions are also based on cross-sectional data and we must therefore be cautious about imposing causal interpretations on the associations between variables we have observed at both the country and the individual level.

Our key finding is that, in countries where trust in science is high, people are also more confident about vaccination, even accounting for their own level of trust in science. We have also shown that the strength of the social consensus in a country that science and scientists are trustworthy *moderates* the macro and micro level relationships between trust in science and vaccine confidence: in countries where consensus that science and scientists can be trusted is high, the positive association between trust in science and vaccination confidence is stronger. This moderating relationship is apparent when considering both the between and the within country

association between trust in science and vaccine confidence, albeit considerably weaker for individual level trust in science. Our findings point to the importance of looking beyond individual level correlates of vaccine confidence to incorporate a consideration of how norms of trust and mistrust of science are produced and maintained in different social contexts. An important avenue for future research will be to identify factors which contribute to the production of societal consensus around trust in science to inform effective public communication strategies around vaccination programmes.

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Acknowledgement: no acknowledgements

Author contributions

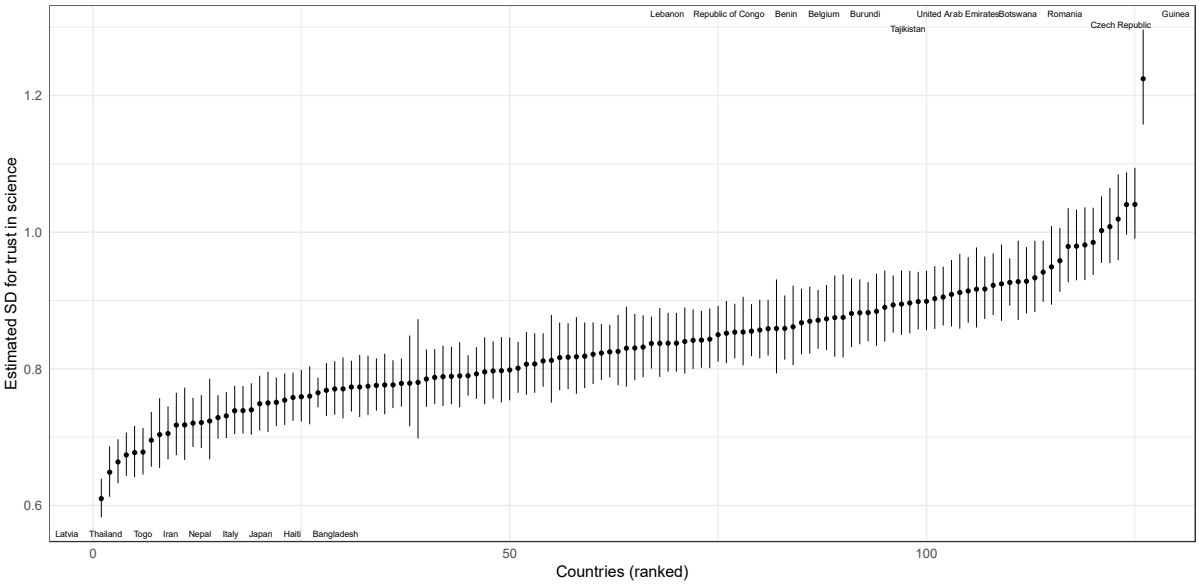
All authors made full and substantial contributions. PS contributed to conceptualization, writing, reviewing and editing; IB-S data processing and analysis, writing and editing, JJ conceptualization, writing.

Competing interests

The authors declare no competing interests.

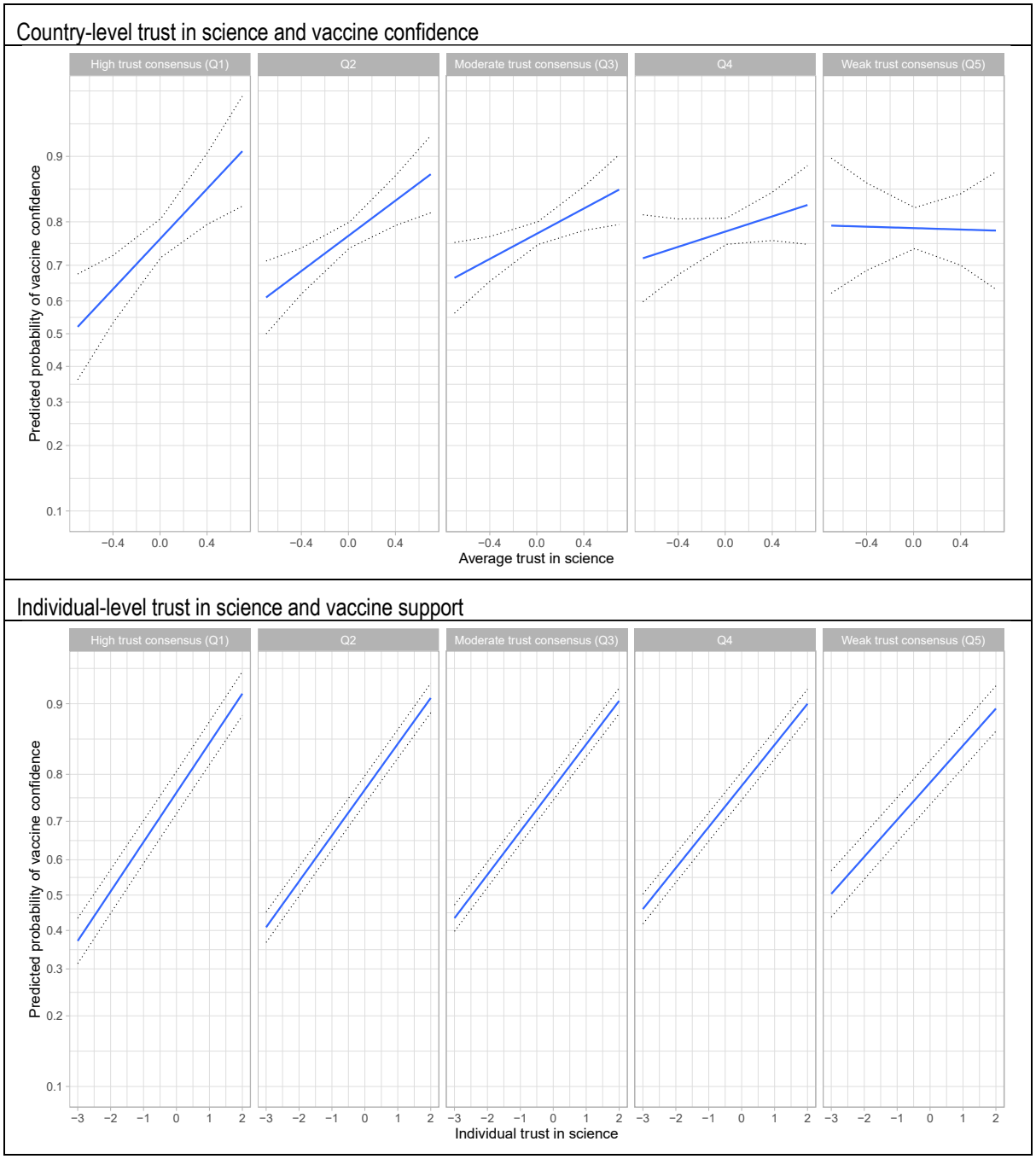
FIGURES

Figure 1. Strength of consensus around trust in science across countries



Data= 2018 Wellcome Global Monitor survey, n=12549, chart shows point estimates and 95% credible intervals of fitted values from the scale equation model in Table 1. The horizontal dotted line is the global mean SD across countries. We identify the countries with the lowest and highest estimated within-country standard deviation.

Figure 2. The strength of consensus around trust moderates the relationship between trust in science and support for vaccines



Data= 2018 Wellcome Global Monitor survey, n=108764, data points are fitted values from Model 2a in Table 2, grey shaded areas are 95% confidence intervals.

Table 1. Location-scale model parameter estimates for trust in science across countries

	B	SD	95% credible interval	
Fixed effects				
Location (mean) equation				
Intercept	-0.014	0.022	-0.058	0.030
Country Predictors				
Gross Domestic Product	0.123	0.029	0.065	0.18
Harmonised Learning Outcome	-0.052	0.033	-0.117	0.014
Gini coefficient	-0.092	0.025	-0.141	-0.043
Individual Predictors				
Male	0.046	0.005	0.037	0.055
Age (10yr intervals)	-0.004	0.001	-0.006	-0.001
Medium education	0.052	0.006	0.039	0.064
High education	0.205	0.008	0.189	0.221
Income (logged)	0.035	0.004	0.028	0.042
Scale (standard deviation) equation				
Intercept	-0.189	0.011	-0.210	-0.168
Country Predictors				
Gross Domestic Product	-0.011	0.013	-0.036	0.015
Harmonised Learning Outcome	-0.034	0.015	-0.063	-0.004
Gini coefficient	0.032	0.011	0.009	0.054
Individual Predictors				
Male	0.032	0.004	0.023	0.040
Age (10yr intervals)	0.012	0.001	0.009	0.014
Medium education	-0.136	0.005	-0.146	-0.126
High education	-0.155	0.007	-0.169	-0.141
Income (logged)	-0.036	0.003	-0.042	-0.03
Random effects				
Standard deviation (*location*)	0.253	0.017	0.222	0.289
Standard deviation (*scale*)	0.114	0.008	0.100	0.131
Correlation of location and scale	0.140	0.091	-0.041	0.316
Individual N	124529			
Country N	126			

Data= 2018 Wellcome Global Monitor survey. All variables were standardised prior to inclusion in the model.

Reported results present the means (B), standard deviations (SD) and 95% uncertainty intervals of the 40,000 monitoring iterations pooled across the four chains. A total of 40,000 warmup iterations were discarded.

Table 2: Interaction model for consensus, trust in science and vaccine confidence

	Overall vaccine support				Important for children				Vaccines are safe				Vaccines are effective			
	Model 1a		Model2a		Model 1b		Model 2b		Model 1c		Model 2c		Model 1d		Model 2d	
	Logit	S.E	Logit	S.E	Logit	S.E	Logit	S.E	Logit	S.E	Logit	S.E	Logit	S.E	Logit	S.E
(Intercept)	1.197**	0.073	1.219**	0.072	3.116**	0.103	3.151**	0.102	1.535**	0.082	1.552**	0.082	1.911**	0.072	1.934**	0.071
Trust in science (individual)	0.489**	0.009	0.499**	0.009	0.581**	0.016	0.590**	0.016	0.505**	0.010	0.515**	0.010	0.551**	0.010	0.558**	0.011
Trust in science (country mean, $\hat{u}_j^{[1]}$)	0.895**	0.299	0.781**	0.300	0.608	0.423	0.434	0.422	1.144**	0.338	1.062**	0.336	0.629*	0.294	0.503	0.293
Strength of consensus ($\hat{u}_j^{[2]}$)			0.455	0.672			0.481	0.944			0.196	0.756			0.482	0.655
Trust mean * strength of consensus			-5.157*	2.565			-8.464*	3.544			-5.685*	2.782			-5.593*	2.454
Trust individual * strength of consensus			-0.459**	0.085			-0.599**	0.133			-0.473**	0.089			-0.430**	0.102
Country	0.66		0.64		1.30		1.23		0.84		0.81		0.63		0.60	
Country N	126				126				126				126			
Individual N	108764				113494				111022				111116			

Data= 2018 Wellcome Global Monitor survey. ** P<.01, * P<.05, all tests are two-tailed

Methods

Data for this study come from the 2018 Wellcome Global Monitor, which was carried out as part of the Gallup World Poll[xxxiii], an annual cross-national survey of adults aged 15+ living in households at non-institutional addresses. The achieved sample size was approximately 1,000 in each of the 144 countries, rising to 2,000 for China, India, and Russia. The data for Cyprus and Northern Cyprus were combined to enable linkage to country level variables that we include in our models. Seventeen countries could not be included in the analysis because they had missing values on the survey variables (2), on the country level variables (14), or both (1). To check the sensitivity of our findings to the exclusion of these countries, we also fitted models using multiple imputation of these missing data. These models produced the same substantive results and are included in the supplementary materials (Tables 2 and 3).

In countries with at least 80% phone coverage, interviews were carried out via Computer Assisted Telephone Interviewing, with face-to-face interviewing used in the remaining countries. For telephone interviews, sampling is implemented through either Random Digit Dialling (RDD) or simple random sampling from nationally representative lists of numbers. Dual frame sampling is used in countries with high rates of mobile phone penetration. Sampling for in-home interviews is implemented in 2-stages, where the first stage selects primary sampling units (PSU) with probability proportional to population size and the second stage selects a random sample of households within each PSU, using the random route method.

The source questionnaire was produced in English, Spanish, and French and then translated using local translators into every language spoken by more than 5% of the resident population in each country using back translation[xxxiv]. A comparison of country level estimates on a range of indicators between the GWP and the European Social Survey and the EU-SILC found high levels of correspondence, with correlations in the range 0.87-0.91[xxxv]. Further detail on the design and fieldwork procedures of the WGM can be found in the Gallup World Poll technical report[xxxvi].

Vaccine confidence is measured using three items from the vaccine confidence scale developed by Heidi Larson and colleagues, which ask respondents to state their level of agreement, on a strongly agree to strongly disagree scale that vaccines are: important for children to have; safe; and effective[xxxvii]. The fourth item from the vaccine confidence scale which asks whether vaccination is consistent with the respondent's religious beliefs was not included in the Wellcome Global Monitor. Due to the high rates of agreement to these items, and following Larson et al (2020), they are recoded to binary variables indicating vaccine confidence, where agree/strongly agree = 1 and all other responses = 0.[xxxviii] A combined measure of overall vaccine confidence was then derived by coding respondents as 1 who agree/strongly agree to all three items and 0 otherwise. Models are fitted for the combined item and for the three items separately.

Trust in science is measured using seven questions. Three ask respondents to state the extent that they: trust scientists in this country; trust science; and trust scientists to find out accurate information about the world. The remaining four items ask respondents how much they trust i) scientists working in colleges or universities and ii) scientists working for companies making medicines or agricultural products to a) do their work with the intention of benefiting the public; and b) be open and honest about who is paying for their work. Response options for these questions were: a lot, some, not much, not at all. The seven items for were combined into a single score using an Item Response Theory model [xxxix]. For *i=1…I* polytomous items with k ordered categories, the probability of observing outcome k or higher for item i and person j is given by

$$\Pr(Y_{ij} \geq k|\theta_j) = \frac{exp\{\alpha_i(\theta_j - b_{ik})\}}{1+exp\{\alpha_i(\theta_j - b_{ik})\}}, \theta_j \sim N(0,1)) \quad [1]$$

Where α_i is the discrimination of item i and b_{ik} is the difficulty of responding with category k or higher, and θ_j is the latent trait measuring overall trust in science. The results for this model are included in the supplementary materials, Table 1.

The WGM also includes a question on trust in medical and health advice from medical workers. To assess the robustness of our findings we also fitted models using these items instead of the 7-item trust scale and this produced the same pattern of results (see Tables 4 and 5 in the supplementary materials).

In addition to our focus on individual and country levels of trust in science, we also assess how the strength of societal consensus that science can be trusted is related to vaccine confidence. We operationalize the strength of societal consensus as the within-country heterogeneity around the average level of scientific trust. In countries where the standard deviation of the trust measure is smaller, we take this as indicating greater consensus between citizens that science and scientists can be trusted, and vice versa (see Browning et al 2016 and Brunton-Smith et al 2018 for existing applications of this approach).

To model country-level heterogeneity in the mean and standard deviation of trust in science, we use a mixed-effects location scale model[xl] [xli] which has the following form, let y_{ij} denote the trust in science score for individual i ($i = 1, \dots, n_j$) living in country j ($j = 1, \dots, J$):

$$y_{ij} = \mathbf{x}'_{ij}\boldsymbol{\beta} + u_j^{[1]} + e_{ij} \quad (2)$$

where $\mathbf{x}_{ij}$ is a vector of individual- and country-level covariates with coefficient vector $\boldsymbol{\beta}$, $u_j^{[1]}$ is a random intercept representing unobserved influences common to all individuals in country j, and e_{ij} is the level-1 residual. Unlike a standard two-level model we relax the assumption of a common level-1 variance by specifying

an auxiliary log-linear equation for the level-1 standard deviation, σ_e , as a function of covariates and an additional country random effect (our focus on the standard deviation reflects the location-scale model implementation in R which differs from some existing applications where the variance is used, although in practice this choice has little effect on the substantive interpretation of model parameters).

$$\ln\left(\sigma_{e_{ij}}\right) = \mathbf{w}'_{ij}\boldsymbol{\alpha} + u_j^{[2]} \quad (3)$$

Here $\ln\left(\sigma_{e_{ij}}\right)$ is the log of the now heterogeneous within-country standard deviation, $\mathbf{w}_{ij}$ is a vector of individual- and country-level covariates with coefficient vector $\boldsymbol{\alpha}$, and $u_j^{[2]}$ is an additional country random effect. The '$[2]$' superscript distinguishes this random effect from the country-level random effect in equation 2. Positive coefficients in $\boldsymbol{\alpha}$ indicate characteristics associated with more variable trust in science assessments, while negative coefficients indicate the opposite. The location and scale random effects are assumed to have bivariate normal distributions and are alllowed to covary. These can then be used to derive posterior estimates of the country specific residuals, $\hat{u}_j^{[1]}$ and $\hat{u}_j^{[2]}$. It would be preferable to include the IRT model as part of the location-scale model because failure to do this means that we do not properly account for random errors in the individual level fitted values. However, it is not yet possible to include latent variables in this way using currently available software and we consider it unlikely that this has any notable effect on our main results and conclusions.

A positive covariance between location and scale effects can be induced where the distribution of the response variable is skewed as a result of 'floor' or 'ceiling' effects[xlii]. However, this is not a concern here because the distributions of the mean and variance in trust in science across countries is normally distributed and the correlation between the posterior residuals is just 0.140 (the correlation for the unadjusted residuals is -0.198).

We control for characteristics of individuals and countries that might be correlated with both trust in science and vaccine confidence, with our selection of variables guided by existing cross-national studies of trust in science and vaccine confidence[xliii] [xliv]. We have opted for a parsimonious model specification in order to maximise the number of countries available for analysis, given the large amount of missing data on the country level variables. At the country level we control for GDP per capita, the GINI measure of income inequality (www.worldbank.org), and the Harmonised Learning Outcome[xlv]. All country level measures are standardized to aid interpretation. At the individual level, we include controls for gender, age, education level, and logged income. Models are estimated in Stan using the R package BRMS with a total of 4 chains and 20,000 iterations each[xlvi].

To assess how individual and country-level trust in science are related to support for vaccination, we fit multilevel binary logistic regression models[xlvii] including the posterior residuals from the location and scale equations measuring overal trust and consensus at level-2.

$$\log\left(\frac{\pi_{ij}}{1-\pi_{ij}}\right) = \beta_{0j} + \beta_1 x_{1ij} + \beta_2 \hat{u}_j^{[1]} + \beta_3 \hat{u}_j^{[2]} + \beta_4 \hat{u}_j^{[1]}.\hat{u}_j^{[2]} + \beta_5 x_{1ij}.\hat{u}_j^{[2]} + u_j \quad [4]$$

Where x_{1ij} is trust in science for individual *i* in country *j*, $\hat{u}_j^{[1]}$ is the residual difference from the mean level of trust in science for country *j*, $\hat{u}_j^{[2]}$ is the residual difference on the scale equation (our measure of societal consensus) for country *j*, u_j is the country level random effect and β_1 to β_5 are the regression coefficients.

Data availability

The Wellcome Global Monitor data set (http://doi.org/10.5255/UKDA-SN-8466-2) used in this paper can be downloaded from the UK Data Service website here:

https://beta.ukdataservice.ac.uk/datacatalogue/studies/study?id=8466

Code availability statement

The R code used to fit the models in this paper is available via GitHub here:

https://github.com/PatrickSturgis/Trust-in-science-social-consensus-and-vaccine-confidence

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