Association of vaccine hesitancy and immunization coverage rates in the European Union

Florian Stoeckel, University of Exeter
Charlie Carter, London School of Economics
Ben Lyons, University of Utah
Jason Reifler, University of Exeter

Key words:
Vaccine hesitancy, immunization coverage, European Union, vaccination coverage, public health policy, surveys

While previous studies have validated vaccine hesitancy scales with uptake behavior at the individual level, the conditions under which aggregated survey data are useful are less clear. We show that vaccine public opinion data aggregated at the subnational level can serve as a valid indicator of aggregate vaccine behaviour. We use a public opinion survey (Eurobarometer EB 91.2) with data on vaccine hesitancy for the EU in 2019. We link this information to (subnational) regional immunization coverage rates for childhood vaccines – DTP3, MCV1, and MCV2 -- obtained from the WHO for 2019. We conduct multilevel regression analyses with data for 177 regions in 20 countries. Given the variation in vaccine hesitancy and immunization rates between countries and within countries, we affirm the valuable role that surveys can play as a public health surveillance tool when it comes to vaccine behavior. We find statistically significantly lower regional vaccine immunization rates in regions where vaccine hesitancy is more pronounced. Our results suggest that different uptake rates across subnational regions are due, at least in part, to differences in attitudes towards vaccines and vaccination. The results are robust to several checks.

Forthcoming Vaccine 39 (2021) pp. 3935-3939
https://doi.org/10.1016/j.vaccine.2021.05.062

Acknowledgements:

Florian Stoeckel reports funding from the British Academy (SRG20\200348). Jason Reifler received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (grant agreement No 682758).

Corresponding author:
Dr Florian Stoeckel
University of Exeter
f.stoeckel@exeter.ac.uk

Background

Scholars have given increasing attention to "vaccine hesitancy" (Larson et al., 2014). Owing to the potential dangers of vaccine hesitancy, the Strategic Advisory Group of Experts [SAGE] on Immunization established a Working Group dealing with vaccine hesitancy in March 2012 (SAGE, 2012), and due to hesitancy's continued acceleration, the Lancet recently announced a Commission on Vaccine Refusal, Acceptance, and Demand in the USA (Hotez et al., 2021). Concerns about vaccines may then translate into refusal or delay of some vaccines, total refusal, or even total acceptance despite concern. Previous research has found that there is a link between aggregate levels of vaccine hesitancy and vaccine uptake in different contexts and for different vaccines. We extend this line of inquiry to subnational levels in the European context.

A number of systematic reviews have summarized the research on determinants of and potential solutions to vaccine hesitancy (e.g., Larson et al., 2014; Jarret et al., 2015; Dube et al., 2015; Salmon et al., 2015). Further, a number of scales have been developed to measure hesitancy in surveys. These include the Vaccine Confidence Scale (VCS) (Gilkey et al., 2014); Parental Attitudes about Childhood Vaccines (PACV) (Opel et al., 2011); Parental Perspectives Regarding Vaccines Scale (Freed et al., 2010; Nyhan et al. 2014); the Vaccination Attitudes Examination (VAX) Scale (Martin et al., 2017); the Vaccine Attitude Scale (Horne et al., 2015); and the SAGE Working Group's Vaccine Hesitancy Scale (Larson et al., 2015), among others.

Validation at individual level

Do vaccine hesitancy scales measure an attitude that is related to behaviour? At the individual level, this appears to be the case. Opel et al. (2013) validated the PACV among 437 new parents in Seattle, WA in 2010, examining children's immunization status using

GHC electronic immunization records cross-referenced with the state's central immunization registry. They concluded that scores on the PACV predict childhood immunization status and have high reliability. This group also validated the PACV in Seattle in 2013 (Strelitz et al., 2015) using medical records, focusing on influenza vaccine refusal among 152 parents, finding higher hesitancy scores associated with refusal. Roberts et al. (2015) used medical records to validate a version of the PACV modified for the adolescent setting, surveying 363 parents in Oklahoma and South Carolina. They found that several individual items were associated with vaccine uptake, but the modified PACV scale itself was not associated with vaccination status. Finally, Gilkey et al. (2016) validated the VCS among a population-based sample of 9,354 U.S. parents who completed the 2011 National Immunization Survey household survey. This survey included self-reported vaccination status that was subsequently verified by healthcare providers in the 2011 NIS provider survey using medical records. Vaccination confidence was consistently associated with early childhood vaccination behavior across multiple vaccine types. Overall then, validation studies conducted at the individual level suggest hesitancy and vaccination behaviour are likely related, though not every study finds this is the case (e.g., Roberts et al., 2015).

Use at aggregate levels

Hesitancy has also been included on cross-national surveys such as the Eurobarometer, and may be used in essence as a "surveillance" or "monitoring" system (de Figueiredo et al., 2020) for detecting national-level trends regarding vaccination (e.g., in the EU see Larson et al., 2018; see also Larson et al., 2016; Lunz, Trujillo & Motta, 2020). Santibanez et al. (2020) have validated this approach at the subnational level in the US with their finding that states with higher state-level estimates of parental vaccine hesitancy have lower state-level child influenza vaccination coverage. We extend this approach to the

European context by aggregating individual level data from national surveys to produce sub-national estimates of vaccine hesitancy and examine their association with vaccine uptake at the same sub-national levels. Vaccine confidence is particularly low in Europe compared to other continents (de Figueiredo et al., 2020; Larson, 2018; Larson et al., 2018), and there is considerable heterogeneity within Europe, with confidence declining in Czech Republic, Finland, Poland, and Sweden but rising in France, Greece, Italy, and Slovenia since 2015 (Larson et al., 2018).

Data and Method

Study design and population

We conduct an ecological analysis that links aggregated survey data on vaccine hesitancy to subnational vaccine uptake rates. Data on immunization coverage rates comes from the WHO and is publicly available on request at https://www.who.int/immunization/monitoring_surveillance/data/subnational/en/. We obtained subnational immunization coverage data for DTP3, MCV1, and MCV2 for the year of our survey data (2019). A robustness check with uptake data for 2018 can be found in the appendix (Tables A7 and A8), but hesitancy data is only available in the Eurobarometer EB 91.2 from 2019 (which is why we focus on 2019 uptake data). DTP3 is the third dose of the diphtheria, tetanus toxoids, and pertussis–containing vaccine. MCV1 is the first dose of the measles-containing vaccine, MCV2 is the second dose. We focus on MCV1, MCV2, and DTP3 because they are widely used in related vaccine coverage validation and vaccine hesitancy studies (e.g., Anand et al., 2007; Arsenault et al., 2017; Bechini et al., 2019; Murray et al., 2003) and they are also among the vaccines for which the WHO possesses the most complete data. Subnational divisions in the data are based on the EU's nomenclature of territorial units for statistics (NUTS), which is used to subdivide member states' territory from larger (NUTS 1) to smaller (NUTS 3) territorial units. Not all countries have every level of division, depending on their size. In Ireland, the WHO data does not correspond to NUTS regions but instead to Local Health Office (LHO) areas. We obtained information from Health Service Executive Ireland to align the data. Subnational coverage rates for these vaccines serve as our outcome variables.

Data on vaccine hesitancy comes from the Eurobarometer survey of Spring 2019 (EB 91.2). The survey was conducted face to face with probability samples from each EU member state in March 2019. It includes about 1,000 respondents from each country except for Luxembourg, Cyprus, and Malta, where about 500 individuals were interviewed. This yields a total sample size of 27,524 respondents. Our analysis is carried out at the lowest regional level for which we have data for our outcome variable vaccine uptake, albeit the data is available at a lower NUTS level in some countries than in others. While it would be preferable for all data to be at an equally low level (e.g. NUTS3), we pool different NUTS levels to retain as many within country observations as possible (for similar approaches, see e.g. Mohl and Hagen, 2010). Results for a robustness check in which we aggregate data up to the same level (NUTS2) can be found in the appendix. Our analysis of the relationship between hesitancy and DTP3 uptake includes 176 regions from 20 countries, it includes 177 regions in 20 countries for MCV1 and 142 regions in 15 countries for MCV2.

Scale description and measures

Vaccine coverage rates are calculated by dividing the number of vaccine doses that were administered in a district by the target population of the district (i.e., the number of children in case of MCV1, MCV2, and DTP3). While the literature agrees on the importance of measuring vaccine hesitancy, the specific items to do so differ widely. The Eurobarometer survey does not rely on items from the scales reviewed above, but does include a range of questions that allows us to build an index with five items, following suggestions from the literature for multiple-item scales (Martin & Petrie 2017, Horne et al., 2015, Opel et al., 2011). Each of five vaccine hesitancy items offers four response options on Likert style response scales, where the least vaccine hesitant answer is coded as 0 and the most vaccine hesitant answer is coded as 3. The vaccine hesitancy score for each respondent is their average across the five items. To calculate the regional vaccine hesitancy score, we take the average of the individual level vaccine hesitancy score for all respondents in a region. The results we present are restricted to parents, as is typical for studies of childhood immunization, e.g., Santibanez et al. (2020). (Parents are defined as individuals who live together with their children in one household.) Additional analyses in the appendix include analyses based on the full sample rather than just parents. We drop respondents who did not select one of the four substantive response categories. We apply the weights provided by the Eurobarometer when aggregating scores to produce regional hesitancy measures.

The MCV1, MCV2, and DTP3 vaccinations are mandatory in some of the countries in our sample (see Table 2). We use a control variable to account for this difference in all models. Results for models without this control and just for countries without mandate are in the appendix (see appendix Tables A2 and A8).

< Table 1: Question wording >

Statistical Analyses

We use multilevel models to analyse the relationship between hesitancy and vaccine uptake (with a linear link function) because they account for the particular structure of our data: subnational observations being nested within countries. These models are also well suited to a situation in which variation is between countries and within countries. In our case, half of the variation in vaccine uptake is between countries while the remainder of the variation results from variation within countries.

Regional hesitancy scores are based on aggregations from samples with an unequal number of observations. We do several robustness checks that are common in the literature to take into account that this might affect the results. The first approach is based on the fact that we have more confidence in regional hesitancy scores derived from large samples than in those coming from small samples. To account for this we follow previous research (Carle, 2009, Charron et al., 2016) by weighting observations by the sample-size based uncertainty around regional hesitancy estimates. (We include the inverse of the standard errors of regional hesitancy means as weights in the multilevel models.) Our second robustness check corrects for the chance that the composition of the regional samples might differ from the actual population of a region. (This problem should be expected as samples that are nationally representative may not be perfectly representative at subnational levels.) Multilevel regression with post-stratification (MRP) is a common tool for this correction (Downs & Carlin, 2019, Loux et al., 2019). We collected information on the age and gender composition of the regions in our analysis and use MRP to re-estimate regional vaccine hesitancy that takes this composition into account. In a third robustness check (appendix Tables A3), we exclude all regions in which vaccine hesitancy scores were calculated based on fewer than 25 respondents. (To account for the loss of statistical power from removing regions for this analysis, we pool the three vaccines into a single model and account for the resulting clustering.) The results of these robustness checks reinforce our findings.

Results

Vaccine uptake differs both between countries and within countries (see Table 2). For instance, average country level DTP3 uptake varies between 86.26 percent (in Romania) and

99.87 percent in Hungary. Country averages conceal a considerable amount of variation within countries. While MCV1 uptake is relatively similar across regions in Hungary (which must be the case given the extremely high reported uptake rate), there is much variation in other countries (e.g., uptake in Croatia ranges from 73.24 percent to 98.38 percent).

We also find that vaccine hesitancy varies considerably across countries and sub-nationally (see the appendix for details). Average country level vaccine hesitancy is lowest in Denmark and highest in Latvia. In fact, the least vaccine hesitant sub-national region in Latvia is more vaccinate hesitant than the most vaccine-hesitant region in Denmark.

< Table 2: Descriptive data >

We find a relationship between vaccine hesitancy scores and uptake rates of DTP3, MCV1, and MCV2 , though the results differ between specifications (see Figure 1 and Table 1 in the appendix). We find vaccine hesitancy to be associated with DTP3 uptake (95% CI -3.658, -0.035) , MCV1 uptake (95% CI -5.495, -0.779) , and MCV2 uptake (95% CI -5.706, -0.264). When taking uncertainty around regional estimates into account, we still find hesitancy to be related with DTP3 uptake (90% CI -3.139, -0.100) , MCV1 uptake (95% CI -4.933, -0.186) , and MCV2 uptake (95% CI -6.069, -0.520). The results hold when hesitancy scores were calculated using MRP (DTP3: 95% CI -6.714, -0.074 ; MCV1: 95% CI -9.528, -1.169 ; MCV2: 95% CI -10.832, -0.282).

< Figure 1: Regression results for the association of vaccine hesitancy and vaccine uptake >

We probe the nature of the relationship in several additional ways. First, our main model pools countries with and without vaccination mandates as there is variation in vaccine uptake even where mandates exist. The results also hold for DTP3 and MCV1 when estimated just with the sample of countries that have no mandate in place (appendix Table A8; note that this leads to a much smaller number of observations). Second, our main model pools observations from different NUTS levels in order for us to use the fine-grained data that is available and to avoid losing precision from aggregating up lower level data. We also conduct a robustness check in which we aggregate up lower level data in order for the analysis to be based on the same level (NUTS2). The effects are consistent with the ones we find in the main model, but the number of observations is much smaller and standard errors are larger (hence fewer effects are statistically significant; appendix Table A4). Finally, we find that the results hold when we include all respondents rather than just parents (appendix Table A6). This suggests that in some cases, even survey data that lacks measures of parenthood may be useful in monitoring hesitancy at the regional level.

Discussion

Our findings have several implications. First, public immunization rates are related to observed levels of vaccine hesitancy. Uptake rates are lower in regions where hesitancy is more pronounced. The upshot of this finding is that as a surveillance tool, public opinion surveys can be used to understand where vaccines are more likely to be rejected and who should be the target of information campaigns. Our findings complement those showing negative associations of subnational estimates of parental vaccine hesitancy with child vaccination coverage in the U.S (Santibanez et al., 2020). We extend the scope of this finding in several ways, including geographic (cross-nationally in the E.U.), the vaccinations of concern (DTP3, MCV1, and MCV2), and the potential sample of interest (showing association both among parents and within the general population). By looking at the association between vaccine hesitancy and vaccine uptake at the regional level, it may be possible to identify areas that perform extremely well in terms of vaccination relative to hesitancy levels (perhaps drawing lessons of best practice that could be applied elsewhere) as well as identifying areas that are underperforming (where adopting best practices or using other interventions may be especially likely to be successful).

A second implication of our findings is that we do not presently have ideal data on vaccine coverage rates and vaccine hesitancy, even though such data seems valuable to monitor public health issues. For instance, the WHO does not have coverage rates for six EU member states for the vaccines that are included in our analysis. Publicly available influenza vaccine uptake data is even more incomplete: at present, uptake data is only available for 19 countries in 2019, and regional data is unavailable. Regarding vaccine hesitancy, it is valuable that the Eurobarometer 91.2 included such questions, as it is rare that a large-scale cross-country dataset does so. Such efforts could be improved by including question items from the most commonly used hesitancy scales, which would also foster the comparability across studies. Finally, an important share of variation in vaccine hesitancy is at the regional level within countries, rather than simply at the cross-national level. Consequently, we encourage larger and more representative samples at the regional level. (Representative here may mean of the general population or appropriate target populations, such as parents.) We recognize that resources for surveillance surveys may be finite; while we accept the tradeoff for larger and more representative samples at the regional level, others may be less willing to do so. Along these lines, we encourage future work to consider the extent to which vaccine hesitancy measured in surveys is better as a leading or trailing indicator of vaccination uptake, and at what time lag.

The WHO is careful to list the limitations of the vaccine uptake data and these limitations apply to our analysis of this data (https://www.who.int/immunization/monitoring_surveillance/data/limitations.pdf?ua=1). One of the limitations is that uptake data can be imprecise and uptake rates can be above one hundred percent if more children get vaccinated in a region than are registered there (which sets the target): this might occur for instance when many more children get vaccinated in a region where they are not registered.

We use a survey that is designed to represent populations at the national level, but we use it to gauge regional vaccine hesitancy. While we probe the robustness of this procedure, it is less accurate than a survey which is devised for this purpose, with large and equally sized regional samples that are designed to be representative of regional populations.

Conclusion

We found that across the E.U., greater rates of vaccine hesitancy as measured by the Eurobarometer were associated with lower uptake of DTP3, MCV1, and MCV2 vaccines. This finding suggests vaccine hesitancy as measured at aggregated levels can be useful for monitoring potentially problematic regions and guiding interventions. Strategies to improve large national and cross-national public opinion surveys would further improve the usefulness of vaccine hesitancy as a monitoring tool for health professionals.

References

Anand, S., & Bärnighausen, T. (2007). Health workers and vaccination coverage in developing countries: an econometric analysis. The Lancet, 369(9569), 1277-1285.

Arsenault, C., Harper, S., Nandi, A., Rodríguez, J. M. M., Hansen, P. M., & Johri, M. (2017). Monitoring equity in vaccination coverage: a systematic analysis of demographic and health surveys from 45 Gavi-supported countries. Vaccine, 35(6), 951-959.

Bechini, A., Boccalini, S., Ninci, A., Zanobini, P., Sartor, G., Bonaccorsi, G., ... & Bonanni, P. (2019). Childhood vaccination coverage in Europe: impact of different public health policies. Expert review of vaccines, 18(7), 693-701.

Brown, C., Clayton-Boswell, H., Chaves, S. S., Prill, M. M., Iwane, M. K., Szilagyi, P. G., ... & Hall, C. B. (2011). Validity of parental report of influenza vaccination in young children seeking medical care. Vaccine, 29(51), 9488-9492.

Carle, A.C., (2009). Fitting multilevel models in complex survey data with design weights: Recommendations. BMC Medical Research Methodology, 9(1), 49.

Charron, N., Dahlström, C., Fazekas, M. and Lapuente, V., (2017). Careers, Connections, and Corruption Risks: Investigating the impact of bureaucratic meritocracy on public procurement processes. The Journal of Politics, 79(1), 89-104.

de Figueiredo, A., Simas, C., Karafillakis, E., Paterson, P., & Larson, H. J. (2020). Mapping global trends in vaccine confidence and investigating barriers to vaccine uptake: a large-scale retrospective temporal modelling study. The Lancet, 396(10255), 898-908.

Downes, M., & Carlin, J. B. (2020). Multilevel regression and poststratification as a modeling approach for estimating population quantities in large population health studies: A simulation study. Biometrical Journal, 62(2), 479-491.

Dubé, E., Gagnon, D., & MacDonald, N. E. (2015). Strategies intended to address vaccine hesitancy: Review of published reviews. Vaccine, 33(34), 4191-4203.

Freed, G. L., Clark, S. J., Butchart, A. T., Singer, D. C., & Davis, M. M. (2010). Parental vaccine safety concerns in 2009. Pediatrics,125(4), 654–659.

Gilkey, M. B., Magnus, B. E., Reiter, P. L., McRee, A. L., Dempsey, A. F., & Brewer, N. T. (2014). The Vaccination Confidence Scale: a brief measure of parents' vaccination beliefs. Vaccine, 32(47), 6259-6265.

Gilkey, M. B., McRee, A. L., Magnus, B. E., Reiter, P. L., Dempsey, A. F., & Brewer, N. T. (2016). Vaccination confidence and parental refusal/delay of early childhood vaccines. PloS one, 11(7), e0159087.

Hotez, P. J., Cooney, R. E., Benjamin, R. M., Brewer, N. T., Buttenheim, A. M., Callaghan, T., ... & Omer, S. B. (2021). Announcing the Lancet Commission on Vaccine Refusal, Acceptance, and Demand in the USA. The Lancet, 397(10280), 1165-1167.

Horne, Z., Powell, D., Hummel, J. E., & Holyoak, K. J. (2015). Countering antivaccination attitudes. Proceedings of the National Academy of Sciences, 112(33), 10321-10324.

Jarrett, C., Wilson, R., O'Leary, M., Eckersberger, E., & Larson, H. J. (2015). Strategies for addressing vaccine hesitancy–A systematic review. Vaccine, 33(34), 4180-4190.

Larson, H. J. (2018). The state of vaccine confidence. The Lancet, 392(10161), 2244-2246.

Larson, H. J. et al. (2018) State of Vaccine Confidence in the EU 2018, Luxembourg: Publications Office of the European Union. doi: 10.2875/241099.

Larson, H. J., Jarrett, C., Eckersberger, E., Smith, D. M., & Paterson, P. (2014). Understanding vaccine hesitancy around vaccines and vaccination from a global perspective: a systematic review of published literature, 2007–2012. Vaccine, 32(19), 2150-2159.

Larson, H. J., Jarrett, C., Schulz, W. S., Chaudhuri, M., Zhou, Y., Dube, E., ... & Wilson, R. (2015). Measuring vaccine hesitancy: the development of a survey tool. Vaccine, 33(34), 4165-4175.

Larson, H. J., De Figueiredo, A., Xiahong, Z., Schulz, W. S., Verger, P., Johnston, I. G., ... & Jones, N. S. (2016). The state of vaccine confidence 2016: global insights through a 67-country survey. EBioMedicine, 12, 295-301.

Larson, H., de Figueiredo, A., Karafillakis, E., & Rawal, M. (2018). State of vaccine confidence in the EU 2018. Luxembourg: Publications Office of the European Union, 10, 241099.

Loux, T., Nelson, E. J., Arnold, L. D., Shacham, E., & Schootman, M. (2019). Using multilevel regression with poststratification to obtain regional health estimates from a Facebook-recruited sample. Annals of Epidemiology, 39, 15-20.

Lunz Trujillo, K, and Motta, M. (2020). Why Are Wealthier Countries More Vaccine Skeptical?: How Internet Access Drives Global Vaccine Skepticism. APSA Preprints. doi: 10.33774/apsa-2020-bbpld-v2.

Martin, L. R., & Petrie, K. J. (2017). Understanding the dimensions of anti-vaccination attitudes: The vaccination attitudes examination (VAX) scale. Annals of Behavioral Medicine, 51(5), 652-660.

Mohl, P., & Hagen, T. (2010). Do EU structural funds promote regional growth? New evidence from various panel data approaches. Regional Science and Urban Economics, 40(5), 353-365.

Murray, C. J. L., Shengella, B., Gupta, N., Moussavi, S., Tandon, A., & Thieren, M. (2003). Validity of reported vaccine coverage in 45 countries. Health systems performance assessment. Debates, methods and empiricism, 265-271.

Nyhan, B., Reifler, J., Richey, S., & Freed, G. L. (2014). Effective messages in vaccine promotion: A randomized trial. Pediatrics, 133(4), e835–e842.

Opel, D. J., Mangione-Smith, R., Taylor, J. A., Korfiatis, C., Wiese, C., Catz, S., & Martin, D. P. (2011). Development of a survey to identify vaccine-hesitant parents: the parent attitudes about childhood vaccines survey. Human vaccines, 7(4), 419-425.

Opel, D. J., Taylor, J. A., Zhou, C., Catz, S., Myaing, M., & Mangione-Smith, R. (2013). The relationship between parent attitudes about childhood vaccines survey scores and future child immunization status: a validation study. JAMA pediatrics, 167(11), 1065-1071.

Roberts, J. R., Thompson, D., Rogacki, B., Hale, J. J., Jacobson, R. M., Opel, D. J., & Darden, P. M. (2015). Vaccine hesitancy among parents of adolescents and its association with vaccine uptake. Vaccine, 33(14), 1748-1755.

SAGE (2012). SAGE Working Group on Vaccine Hesitancy http://www.who.int/immunization/sage/sage_wg_vaccine_hesitancy_apr12/en/

Salmon, D. A., Dudley, M. Z., Glanz, J. M., & Omer, S. B. (2015). Vaccine hesitancy: causes, consequences, and a call to action. Vaccine, 33, D66-D71.

Santibanez, T. A., Grohskopf, L. A., Zhai, Y., & Kahn, K. E. (2016). Complete influenza vaccination trends for children six to twenty-three months. Pediatrics, 137(3).

Santibanez, T. A., Nguyen, K. H., Greby, S. M., Fisher, A., Scanlon, P., Bhatt, A., ... & Singleton, J. A. (2020). Parental vaccine hesitancy and childhood influenza vaccination. Pediatrics, 146(6).

Strelitz, B., Gritton, J., Klein, E. J., Bradford, M. C., Follmer, K., Zerr, D. M., ... & Opel, D. J. (2015). Parental vaccine hesitancy and acceptance of seasonal influenza vaccine in the pediatric emergency department. Vaccine, 33(15), 1802-1807.

Table 1: Question wording

		min	max	mean	SD
1	It is important for everybody to have routine vaccinations (0= totally agree, 1=tend to agree, 2=tend to disagree, 3=totally disagree)	0	3	0.59	0.77
2	Not getting vaccinated can lead to serious health issues (0= totally agree, 1=tend to agree, 2=tend to disagree, 3=totally disagree)	0	3	0.65	0.79
3	Vaccines are important to protect not only yourself but also others (0= totally agree, 1=tend to agree, 2=tend to disagree, 3=totally disagree)	0	3	0.50	0.70
4	Vaccination of other people is important to protect those that cannot be vaccinated (e.g. newborn children, immune depressed or very sick people) (0= totally agree, 1=tend to agree, 2=tend to disagree, 3=totally disagree)	0	3	0.53	0.71
5	[List of deseases in previous question] All the diseases mentioned earlier are infectious diseases and can be prevented. Do you think that vaccines can be effective in preventing them? (0= Yes, definitely, 1=Yes, probably, 2=No, probably not, 3=No, not at atll)	0	3	0.57	0.74

Table 2: Country mean and within country variation (range) of vaccine uptake by country for each vaccine. All figures are percentages (share of children who were vaccinated in a region out of all children registered in a region), data for 2019 obtained from the WHO

	Vaccine Hesitancy		DTP3			MCV1			MCV2		
Country	Mean	Range	Mean	Range	Mandatory	Mean	Range	Mandatory	Mean	Range	Mandatory
BE	0.64	0.48-0.80	98.20	97.00-98.90		95.30	94.10-96.20		81.47	75.50-93.40	
BG	0.63	0.48-0.76	93.14	85.10-95.80	✓	94.84	90.48-98.53	✓	92.79	87.59-96.19	✓
CY	0.45	0.40-0.50	95.86	92.80-99.20		85.94	81.20-92.60		—	—	
CZ	0.59	0.47-0.69	96.69	92.87-98.94	✓	92.90	91.40-94.50	✓	—	—	✓
DE	0.47	0.19-0.85	93.29	88.60-96.80		97.47	95.20-98.60		93.29	89.80-96.00	
DK	0.23	0.11-0.48	96.69	95.44-97.00		95.06	93.91-96.00		90.32	87.27-92.00	
EE	0.57	0.44-0.67	91.67	90.07-95.50		88.21	84.66-91.90		89.46	88.10-91.81	
ES	0.40	0.00-0.85	95.94	92.52-98.26		97.75	95.18-99.96		93.81	85.52-99.32	
HR	0.73	0.19-1.38	95.04	84.91-98.86	✓	93.34	73.24-98.38	✓	95.24	84.52-98.97	✓
HU	0.52	0.32-0.78	99.86	99.79-99.90	✓	99.87	99.78-99.93	✓	99.80	99.63-99.90	✓
IE	0.48	0.25-0.59	93.88	91.48-96.52		91.41	88.44-95.44		—	—	
IT	0.67	0.26-1.14	94.83	88.11-97.40	✓	93.89	85.60-96.11	✓	87.54	78.62-93.70	✓
LT	0.64	0.51-0.88	93.01	89.70-96.70		94.21	90.90-96.70		94.90	90.40-98.30	
LV	0.90	0.75-1.01	98.71	91.36-107.42		98.00	87.20-112.00		95.52	81.20-104.00	
NL	0.24	0.10-0.40	93.44	87.62-95.35		93.37	87.56-95.28		90.19	84.79-95.02	
PT	0.37	0.13-0.62	98.64	98.10-99.40		98.68	97.80-99.40		97.20	95.10-98.50	
RO	0.84	0.55-1.13	87.67	83.50-92.02		88.89	79.82-92.26		—	—	
SE	0.31	0.08-0.68	97.40	96.64-97.85		97.20	96.39-97.74		—	—	
SK	0.67	0.35-1.14	96.75	96.52-97.15	✓	95.80	94.81-96.66	✓	97.63	96.92-98.17	✓
UK	0.46	0.05-0.80	93.33	87.00-96.00		91.92	83.00-95.00		88.67	76.00-92.00	

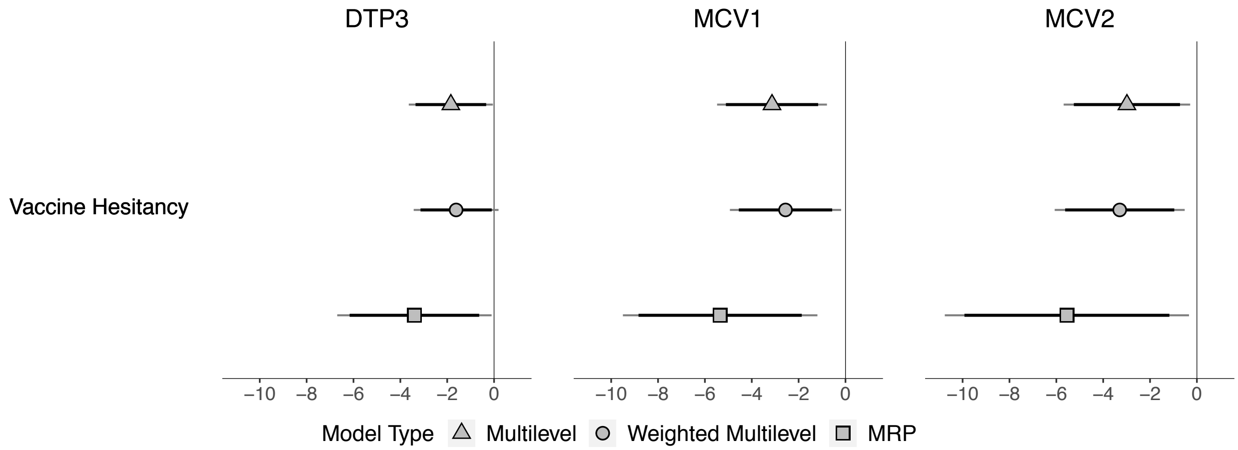

Figure 1: Regression results for the association of vaccine hesitancy and vaccine uptake. Plots show the regression coefficients for regional level vaccine hesitancy on regional level vaccine uptake. Values below zero indicated a negative relationship between vaccine hesitancy and vaccine uptake; as vaccine hesitancy increases in a region, vaccine uptake decreases. Each subfigure reports multiple model specifications to show robustness. Thin lines: 95 percent CI, thick lines 90 percent CI. Models control for mandatory vaccination.