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## Vaccine hesitancy comes in waves: Longitudinal evidence on willingness to vaccinate against COVID-19 from seven European countries



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### ABSTRACT

**Aim:** This paper investigates the prevalence and determinants of three main states of people's willingness to be vaccinated (WTBV) against COVID-19 – willing, unwilling and hesitant – and the occurrence and predictors of shifts between these states over time. Understanding the dynamics of vaccine intentions is crucial for developing targeted campaigns to increase uptake and emergency response preparedness.

**Study design:** A panel survey consisting of 9 quarterly waves of data collected between April 2020 and January 2022. Baseline data included 24 952 adults from Germany, UK, Denmark, the Netherlands, France, Portugal, and Italy recruited from online panels to construct census-matched nationally representative samples.

**Methods and measures:** Self-reported COVID-19 vaccine intention was the main outcome. Multinomial logit random effects models were used to analyze the relationships of interest. All results reported as relative risk ratios (RRR).

**Results:** Hesitancy to get vaccinated was the most unstable vaccine intention, with on average 42% of ever hesitant respondents remaining in this state through future waves, followed by the 'unwilling' (53%) and 'willing' (82%). Following COVID-19 news, trust in information from the government, GPs and the WHO, risk preferences, risk perceptions, and confidence in vaccines (or lack thereof) predicted vaccination intention reversals. Risk preferences acted both as an impediment and as a facilitator for the vaccine uptake depending on the initial vaccine intention.

**Conclusions and relevance:** This study revealed the dynamic nature of COVID-19 vaccine intentions and its predictors in 7 European countries. The findings provide insights to policymakers for designing more effective communication strategies, particularly targeted at hesitant and unwilling to vaccinate population groups, to increase vaccine uptake for future public health emergencies.

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### 1. Introduction

In Europe, the willingness to be vaccinated (WTBV)<sup>1</sup> against COVID-19 has fluctuated over the course of the pandemic, with large

differences across countries [1]. Since the rollout of first effective vaccines against COVID-19 at the beginning of 2021, reaching a sufficient uptake rate among the population to mitigate the spread of the virus became the primary concern of policy makers and public health professionals.

WTBV can be viewed as a proxy for the vaccination uptake [2], and can, therefore, be informative for the design and implementation of effective vaccination programs and information campaigns. Nevertheless, the evidence about the long-term stability of vaccine intentions is relatively sparse and mainly qualitative in nature [3,4]. Vaccine hesitancy is believed to be a dynamic and heterogeneous state that opens doors for persuasion, whereas unwillingness

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<sup>1</sup> WTBV – willingness to be vaccinated.

to vaccinate is generally considered to be a more rigid state characterized by inert preferences and behavior [5–7]. Few studies addressed reversals in COVID-19 vaccine intentions, most of which were limited to specific subpopulations (e.g., healthcare workers, refugees, etc.) [8].

To promote vaccination uptake in the face of public health emergencies, it is important to understand the dynamics of vaccine decision-making in national populations and factors driving different vaccination intentions and reversals thereof. From the policy perspective, hesitant individuals may potentially be the first most relevant group to target as they might be persuaded to take the vaccine, whereas those unwilling to vaccinate may require much more effort and still refuse. Nonetheless, it is still important to understand their motivation, as unvaccinated people may pose a health risk to others with vulnerable health or when clusters of unvaccinated people emerge, even if the overall vaccination rate is high [9]. By understanding the motivations of these different groups in the population, communication strategies about the benefits of and possibilities for vaccination can be tailored more specifically to their needs and interests. Hence this paper aims to find out how COVID-19 vaccine intentions developed across Europe during the pandemic, and which factors predicted switching between being willing, hesitant or unwilling to get vaccinated. It therefore sets two objectives. First, to investigate the prevalence and factors associated with COVID-19 vaccine intentions. Second, to explore the temporal dynamics of COVID-19 vaccine intentions, and factors linked to switching between the WTBV states.

Our paper adds to a growing literature that studies the drivers of COVID-19 vaccine acceptance [10–13], focusing on the switches in vaccine intentions, an underexplored aspect of the vaccination decision-making process. We extend the existing literature by using multi-country longitudinal data purposively collected for studying attitudes and behaviors in relation to the COVID-19 pandemic, covering an extensive pandemic period, and advanced statistical methods, allowing us to identify the predictors of vaccination intentions and intention shifts. To our knowledge, this is the largest multi-country longitudinal study on the WTBV in Europe with adequate follow-up, consisting of 9 waves conducted between April 2020 and January 2022, allowing to use inter-individual differences and intra-individual dynamics for more accurate inferences.

## 2. Methods

### 2.1. Data

Longitudinal data were obtained from 9 waves of the European Covid Survey (ECOS) [1] that collected data in representative samples of the adult population in Denmark, France, Germany, Italy, Portugal, the Netherlands, and the UK between April 2020 and January 2022. The survey received ethical approval from the University of Hamburg. All participants provided informed consent.

The questionnaire was translated into each country's language by native speakers to ensure the homogeneity of questions and comparability of results. It was administered online to around 1 000 respondents in each country using the Qualtrics platform and repeated with the frequency of three months on average.

The participants were recruited from online panels through the market research company Dynata to ensure the representativeness of national samples with respect to region, age, and sex (using national census data). To reach the general population, several recruiting techniques were used (i.e., open recruitment, loyalty programs, mobile apps, or affiliate networks). Quota sampling was used to ensure representativeness in terms of gender, age categories, region, and education (all non-interlocked) in each country

separately using national census data for quotas. In each wave, former respondents were invited first. Around 48% of respondents were followed over two or more waves [14].

### 2.2. Outcome measures

The main dependent variable, WTBV, was elicited with a three-point scale, similar to other COVID-19 related panel studies [15]. We recorded a respondent's WTBV ("Would you be willing to get vaccinated against the novel coronavirus?": yes; no; not sure) as one of the 3 states respectively: willing, unwilling, hesitant. The WTBV question in the survey was asked to all participants regardless of their vaccination status.

The questionnaire asked about respondents' demographic characteristics, such as sex, age (categorized into 6 groups: below 25, 25–34, 35–44, 45–54, 55–64, 65+), education (categorized into low, medium and high levels based on a country-specific education system (eTable 1)), self-assessed measure of household income [16] ("Thinking of your household's total monthly income, would you say that your household is able to make ends meet...": with great difficulty; with some difficulties; fairly easily; easily; categorized into 2 groups: with difficulty and fairly easily), living alone status and having a vulnerable household member (both binary variables).

Additionally, we elicited each respondent's risk preferences through their answers to 2 lottery-type questions [17] (grouped into low, somewhat, very, and extremely risk-averse groups).

Also, respondents self-assessed how closely they follow COVID-related news (not closely, somewhat or very closely), their risk perceptions regarding catching coronavirus, the perceived severity of COVID-19 for the health of their family and for the health of their community (each ranging from 1="no risk" to 5="very high risk", grouped into low, medium and high levels), their beliefs about the safety of vaccines in general [18] ("Overall I believe that vaccines are safe": strongly agree; agree; strongly disagree; disagree; I don't know; categorized into 3 groups: confident, not confident, undecided) used as a lagged variable, and their levels of trust in information from the national government, family doctors (GPs), and the WHO in the context of the COVID-19 situation (each ranging from 1="not at all" to 5="trust very much", grouped into low, medium, and high levels).

In addition, we added country-specific and wave-specific data from stringency index of the Oxford COVID-19 Government Response Tracker [19] as a proxy for the strictness of government policy measures. Furthermore, we controlled for the number of average new COVID-19 cases and deaths per million in the country, and total number of COVID-19 vaccinations per hundred inhabitants per country [20] to account for country- and time-specific contextual factors associated with WTBV that may have indirectly influenced individuals' willingness to be vaccinated.

### 2.3. Statistical analysis

First, we explored the prevalence and determinants of each of the WTBV states based on pooled data from the national representative samples ( $N = 24\,952$ ) modelled through multinomial logit with random effects. Then, we examined transition probabilities between the states and analyzed the shifts between these states using a subsample of individuals whom we observed in at least two consecutive waves ( $N = 10\,187$ ). Here we estimated 3 multinomial logit random effects models (separately for each WTBV state taken as initial) to find out the probability of switching from the initial WTBV state to a different state in the next period. Only switches that occurred between two consecutive periods were accounted for. We chose the reference group at time  $t$  to always be the same group as the reference group at time  $t-1$  to facilitate the interpretation. All models included factor variables indicating

the survey wave and country, and their interactions. We repeated this analysis for individual countries to find out whether any determinants were more pronounced in some of them. No statistical methods were used to impute missing data. The significance level was set at  $\alpha = 0.05$ . To conduct statistical analyses, *xtmlogit*, *xttab* and *xttrans* packages in Stata 17.0 were used.

### 3. Results

#### 3.1. Descriptive statistics

In total, we received 64 194 answers from 24 952 individuals (53% female; mean [SD] age 43.8 [16.8]) who participated in the survey during the study period (48% longitudinal response rate, eTable 2 in the Supplement). Sample descriptive statistics are shown separately for each of the WTBV groups in eTable 3. The willing to get vaccinated group was disproportionately larger than the other two. The differences between the population sub-groups were all statistically significant (eTable 3).

#### 3.2. Prevalence and determinants of the WTBV states

The proportion of people willing to get vaccinated against COVID-19 across Europe changed notably throughout the pandemic (Fig. 1a). While nearly every country exhibited a U-shape pattern in the WTBV, we observed a high degree of heterogeneity. Unwillingness to get vaccinated varied along time and across countries too, peaking at 17% at an aggregate level before the effective vaccine solution was announced in November 2020 and gradually decreasing afterward. Similarly, vaccination hesitancy had been heterogeneous both in terms of time and magnitude before reaching its peak of 23% in November 2020, after which it showed a decreasing trend in all countries. Fig. 1 summarizes the trends observed throughout the pandemic, by WTBV state (Fig. 1a) and by country for each WTBV state (Fig. 1b–1d).

The predictors of the WTBV states drawn from the multivariate multinomial logit model are displayed in Fig. 2 (eTable 4 for specific values). The analysis showed that those stating to be unwilling to get vaccinated shared the same traits as the hesitant. As compared to those willing to get vaccinated, they were more likely to live alone and be extremely risk-averse, while less likely to be male, older, highly educated, make ends meet easily, follow COVID-19 related news closely, or have high level of trust in information from the government, GPs, and the WHO. Lack of confidence in general vaccine safety, low perceived risks and lower stringency index were associated with higher likelihood of becoming unwilling to get vaccinated, but not with the hesitancy. In all cases, individual WTBV in the previous wave was a significant predictor of the WTBV in a current wave suggesting that respondents tended to carry over their preference to the next period.

#### 3.3. Vaccine intention shifts between the WTBV states

We first examined the transition probabilities (Fig. 3 and eTable 5) and stability of each state in each wave (eTable 6), and then explored the predictors of the shifts (Fig. 4 and eTable 7). The flows of survey respondents between the WTBV states along the study period are illustrated in eFigure 1.

The data showed that the ‘willing’ state was the most stable: conditional on an individual ever being willing to get vaccinated, 82% of her observations were observed in this state (eTable 6). On average, each wave 91% of the initially willing to get vaccinated respondents stayed in the willing state, whereas around 3% of them switched to the unwilling state and 7% shifted to the hesitant state (Fig. 3 and eTable 5). The shifts out of the willing state were

mainly observed during the first year of the pandemic and lasted until the vaccination rollout started.

The analysis of the determinants showed that being male, high level of education, making ends meet fairly easily, and high levels of trust in information from the government, GP and the WHO were associated with higher likelihood of staying in the willing state (Fig. 4, left panel). Highly risk-averse people and those aged between 35 and 54 were more likely to switch to a hesitant state.

The hesitant state was the most unstable: ever-hesitant respondent remained hesitant 42% of the observation time (eTable 6). On average, each wave 44% of initially hesitant respondents remained hesitant (eTable 5). People living alone and extremely risk-averse respondents were significantly more likely to stay in this state rather than switch to the willing state (Fig. 4, mid panel). Nevertheless, around 38% of initially hesitant individuals transitioned to the willing state in each wave (eTable 5). These respondents were more likely to be males, meeting ends fairly easily, following COVID-19 news, with high levels of trust in information from the government and the WHO, confident in vaccine safety and with high perceived coronavirus susceptibility (Fig. 4, mid panel). Only high perceived risk of catching coronavirus and lack of confidence in general vaccine safety increased the likelihood of the shift from the hesitant to the unwilling state, which occurred on average in 18% of cases in each wave (mid panel of Fig. 4 and eTable 5).

The unwilling to get vaccinated state was somewhat stable: conditional on an individual ever being unwilling to get vaccinated, 53% of her observations were observed in this state (eTable 6). On average, each wave 69% of initially unwilling to get vaccinated respondents remained in the unwilling state (eTable 5). High risk aversion and lack of general vaccine confidence increased the probability of staying in this state (Fig. 4, right panel). The highest transition probability from the unwilling state was to the hesitant state until the rollout of the vaccination campaigns (April 2021), after which the transition was more likely to happen from the unwilling directly to the willing state (Fig. 3). The share of initially unwilling participants that shifted to the hesitant state amounted to 14% on average each wave (eTable 5). These respondents were more likely to be older than 65, highly trusted in information from the government, GP and the WHO, and perceived risks of catching coronavirus and threat to the health of their family as medium or high (Fig. 4, right panel). The percentage of those who switched directly to the willing state was on average 17% each wave (eTable 5). Male sex, making ends meet fairly easily, confidence in general vaccine safety and at least medium levels of trust in information from the government, GP and the WHO were associated with an increased likelihood of such shift (Fig. 4, right panel).

We repeated the same analysis at the level of individual countries and found out that some of the determinants were more pronounced in certain countries (eTable 8).

#### 3.4. WTBV and actual vaccination behavior

Finally, we examined the WTBV in relation to self-reported vaccination status. Our descriptive analysis showed a consistent pattern, with the proportion of respondents willing to vaccinate closely aligned with the proportion of individuals who had either reported receiving the vaccine or expressed an intention to do so (Fig. 5).

Moreover, we observed that a similar proportion of hesitant individuals transitioned to either a vaccinated or unvaccinated state between survey waves (eFigure 2). In contrast, only a small proportion of unwilling individuals opted to get vaccinated, while a larger share remained persistently unvaccinated.

Additionally, we investigated the possibility that some individuals who were initially willing to vaccinate might have become unwilling after a negative prior experience with COVID-19 vaccina-

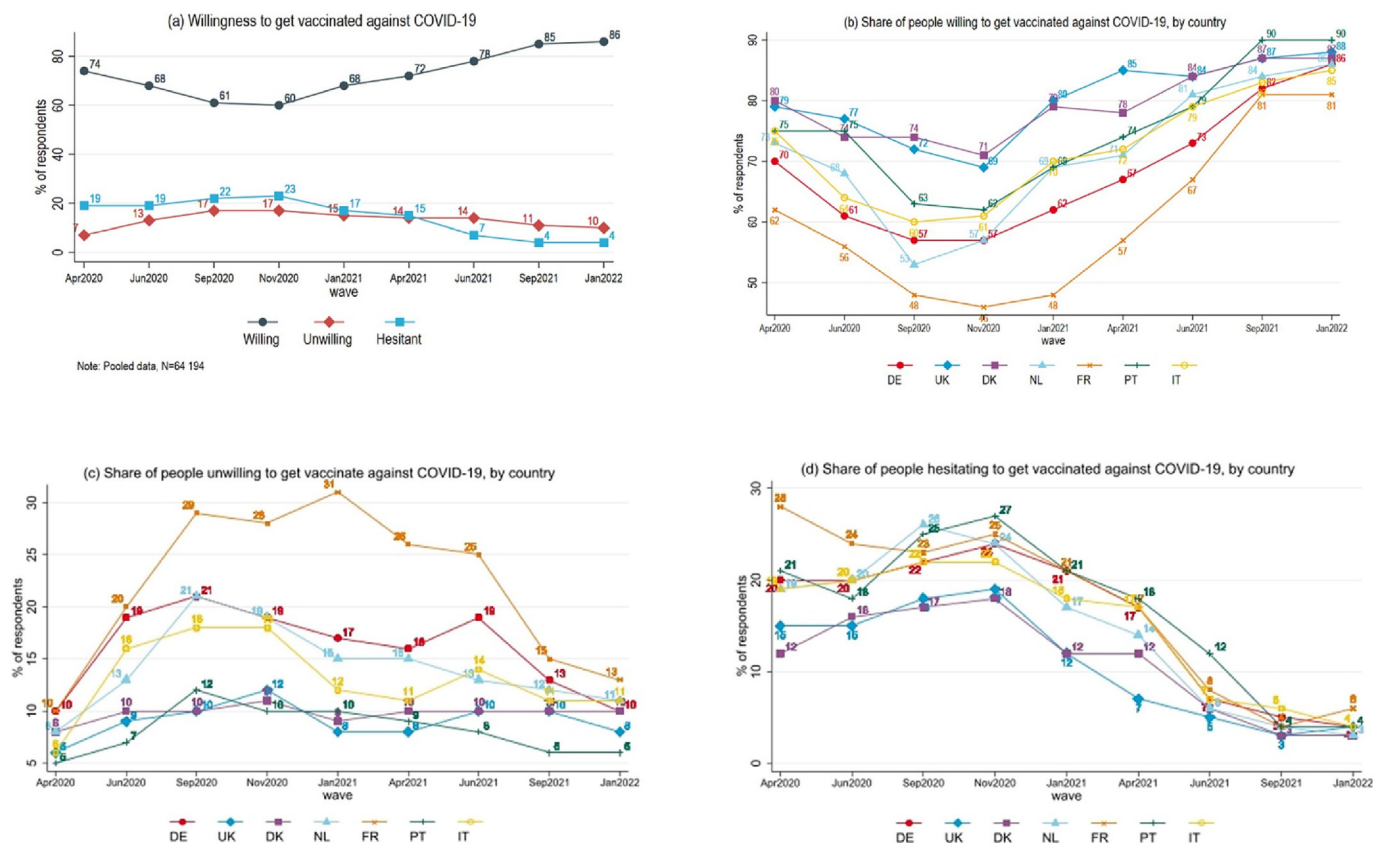


Fig. 1. Prevalence of WTBV states over time and across countries.

tion. Our descriptive analysis (eFigure 3) revealed that while it was indeed possible to receive a vaccine shot but afterward hesitate or become unwilling to vaccinate, the number of such cases was rather negligible (<0.4%). The analysis of the open-ended responses collected from hesitant and unwilling individuals did not reveal any concerns related to prior vaccination experience.

4. Discussion

To our knowledge, this is the largest European cross-country panel study investigating the trajectory of the willingness to be vaccinated against COVID-19 over time. Our analysis covers the period since the earliest days of the pandemic until the second booster vaccination using panel data from several European countries and it sheds light on the likelihood and determinants of change in the willingness to get vaccinated status. We provide unique and novel evidence for targeted vaccination campaigns to enhance the vaccine uptake in Europe, as discussed in the following paragraphs.

4.1. Personal and demographic factors: Unchangeable but influenceable

Our data showed that women had lower willingness to get vaccinated against COVID-19 and lower probability of switching into this state if initially hesitating or being unwilling to get the vaccine. Making ends meet fairly easily and high education level were identified as important factors increasing the probability of initially unwilling or hesitant individuals to become willing to receive a vaccine and keeping people in the willing state. These findings are in line with previous literature highlighting the links between economic hardship, low education levels, gender differences and

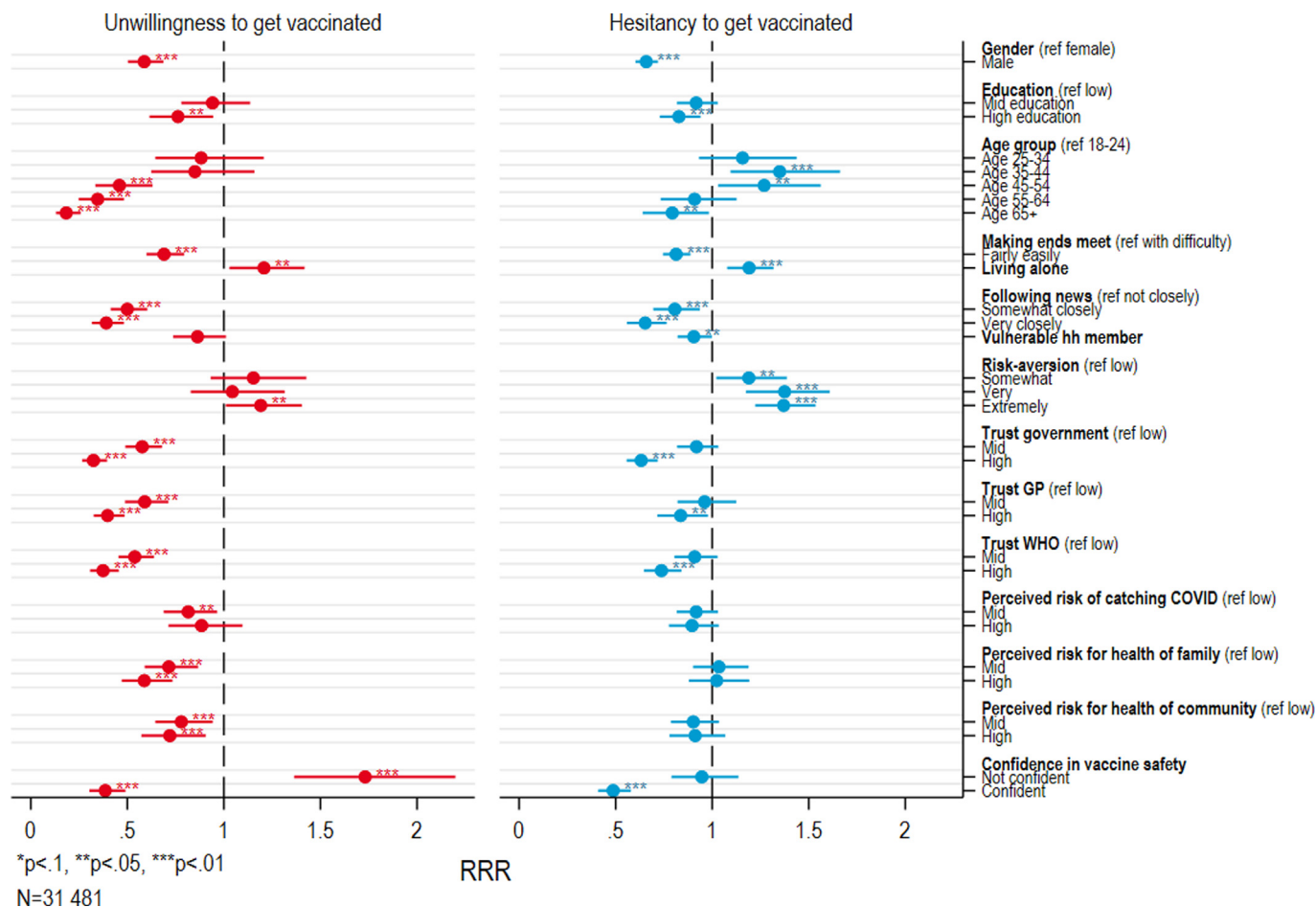
vaccination uptake [21-24]. They highlight the need for tailored communication and appeals, and support the idea of better women (especially female healthcare professionals) involvement and visibility in the decision-making processes, policies and programs development and in the allocation and distribution of healthcare resources at local, national and international levels [25].

High risk-aversion was associated with higher probability of switching into the willing state among initially hesitant and unwilling respondents and increased the likelihood of staying in this state as opposed to moving to the unwilling state. However, it also increased the risk of switching to the hesitant state among initially willing to get vaccinated respondents. Indeed, people had to weigh potential benefits of the vaccine versus possible harm it could cause, and in case of brand-new vaccines against COVID-19, neither risks nor rewards were known with certainty. Our findings introduce risk preferences as a relevant factor that may act both as an impediment and as a facilitator for the vaccine uptake and should therefore be considered when designing vaccination campaigns. For instance, vaccination messaging campaigns may prove more effective if they aim at minimizing risk perception. This finding is consistent with recent research showing that individual differences in risk preferences moderate responses to vaccine-related communications [26].

4.2. Confidence, trust and communication

Confidence in general vaccine safety was found to be associated with higher willingness to get vaccinated and significantly increased probability of initially unwilling or hesitant individuals to become willing to receive a vaccine. Hence, strengthening the general vaccine confidence outside public health emergencies pays off and should be carried out on the continuous basis through com-





**Fig. 2.** Determinants of the WTBV states: results of multivariate multinomial regression model. Pooled data (N = 31 481). Multinomial logit. Referent group: willing to get vaccinated. Exponentiated coefficients presented in terms of relative risk ratios (RRR), standard errors (in parentheses) and confidence intervals transformed accordingly. The RRR of a coefficient indicates the change of the risk of the outcome falling in the comparison group compared to the risk of the outcome falling in the referent group as a result of the change in the explanatory variable. Hence an RRR > 1 implies that the comparison outcome is more likely, whereas an RRR < 1 implies that the outcome is more likely to be in the referent group. \* p < 0.10, \*\* p < 0.05, \*\*\* p < 0.01.

munication and dissemination activities. Since trust in the information from the WHO and GPs was consistently found to be a significant predictor of higher willingness to get vaccinated and was an enabler for the shift to this state, community engagement with healthcare professionals needs to be increased and a pre-emptive communication of the benefit and safety of vaccines (both in general and that of the COVID-specific ones) must be prioritized. A more GP-focused campaign can therefore be an effective policy measure, especially in countries where trust in the information from GPs showed to have high impact (e.g., Germany). GPs could serve as mediating channels ensuring a continuous flow of WHO’s up-to-date scientific information throughout the vaccine development process to the local audience, making the content more comprehensible to the public and alleviating raising concerns thereby serving in the best interest of the public.

Our findings are generally aligned with the existing evidence in the literature for other vaccines showing that the willingness to vaccinate in Europe can be influenced by the mistrust in public health authorities [27], and that willingness to take a vaccine (or absence of it) is an outcome of an individual’s trust in a vaccine, in the wider health system that procures it and in the person who dispenses it or gives advice about vaccination [28,29]. Indeed, in the lack or absence of full understanding of vaccine safety and efficacy (as in case of the COVID-19 vaccine due to its novelty and speed of development), individual decisions whether or not

to vaccinate had to be primarily based on trust in the institutions providing the vaccines and prior experience with them. Our analysis showed that even medium levels of trust in the information from the government, GP and the WHO were sufficient to increase the likelihood of initially unwilling people switching to the willing state, while the analysis of individual countries showed that trust in the information from the government was pronounced in certain countries more than in others. For instance, it was a very important determinant in France, the Netherlands and Germany, but not in Italy or Portugal (table S8), where the vaccine campaign was depoliticized since the very beginning [30,31]. Cross-country differences may be explained by different contexts and features of national immunization programs, as well as by previous experiences of population with vaccine confidence crises. Institutional trust is vulnerable to political conflict and may not be stable over time, hence it may have manifested along the whole spectrum of vaccine hesitancy, unwillingness to vaccinate, non-participation, poor participation, etc. Our findings suggest that linking vaccination campaigns to government actions can make vaccination campaigns vulnerable, while depoliticizing them may, on the contrary, diminish such risk. Therefore, rebuilding trust in public institutions is important, but it is unlikely to be a feasible solution attainable in a short period of time given a public health emergency like COVID-19. Initiating future vaccination campaigns without linking them to the government and letting only specialized highly trusted

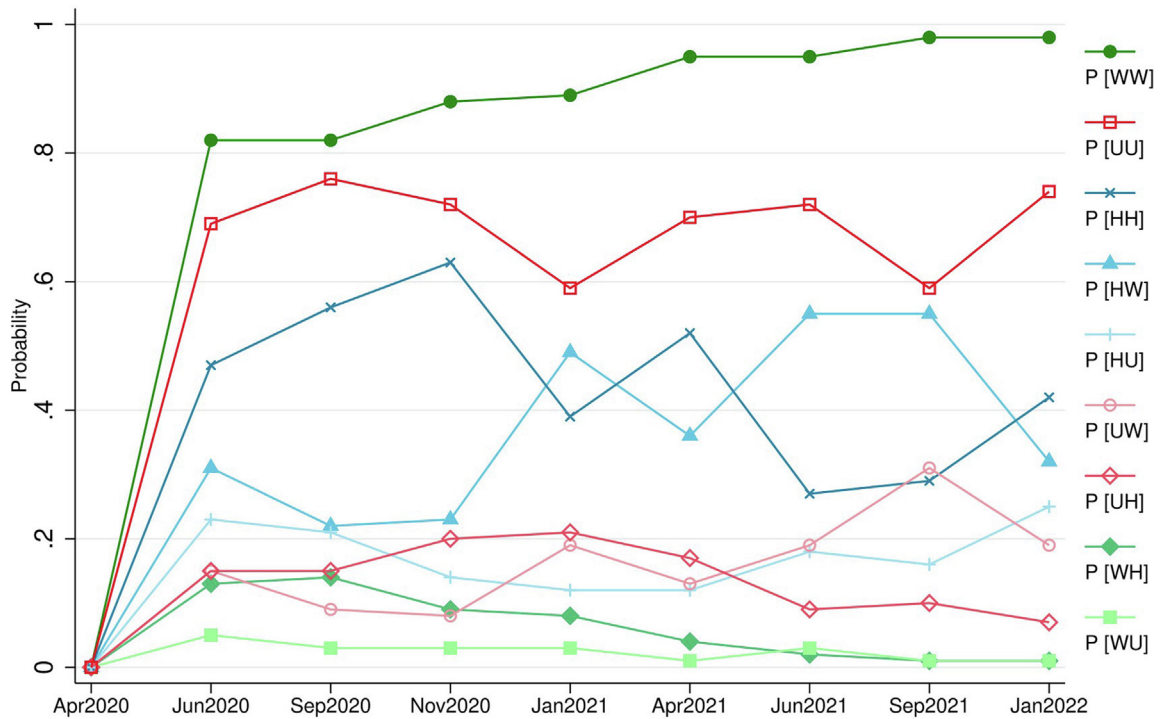


Fig. 3. Transition probabilities between the WTBV states. W – willing, U – unwilling, H – hesitant. P [WW] – transition from willing at t-1 to willing at t, P [WH] – transition from willing at t-1 to hesitant at t, P [WU] – transition from willing at t-1 to unwilling at t, etc. Estimated with the help of *xtrans* package in Stata.

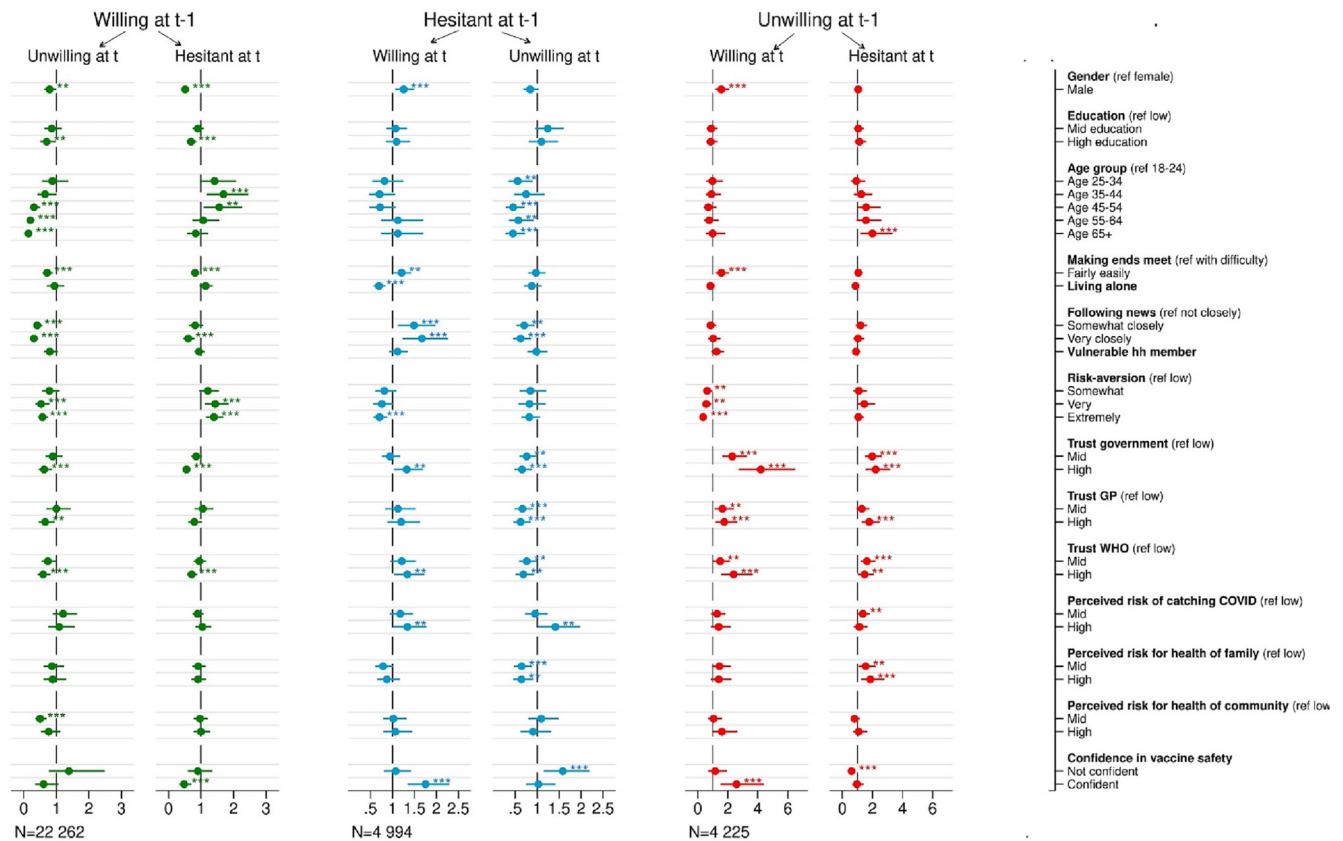


Fig. 4. Results of multivariate multinomial regression model: determinants of switching between states from time t-1 to time t. Pooled data (participants of at least two consecutive waves). Three multinomial logit models (separately for initially willing, hesitant and unwilling individuals). Exponentiated coefficients presented in terms of relative risk ratios (RRR), standard errors (in parentheses) and confidence intervals transformed accordingly. Relative Risk Ratios (RRR > 1 implies that the comparison outcome is more likely, whereas an RRR < 1 implies that the outcome is more likely to be in the reference group). \* p < 0.10, \*\* p < 0.05, \*\*\* p < 0.01.

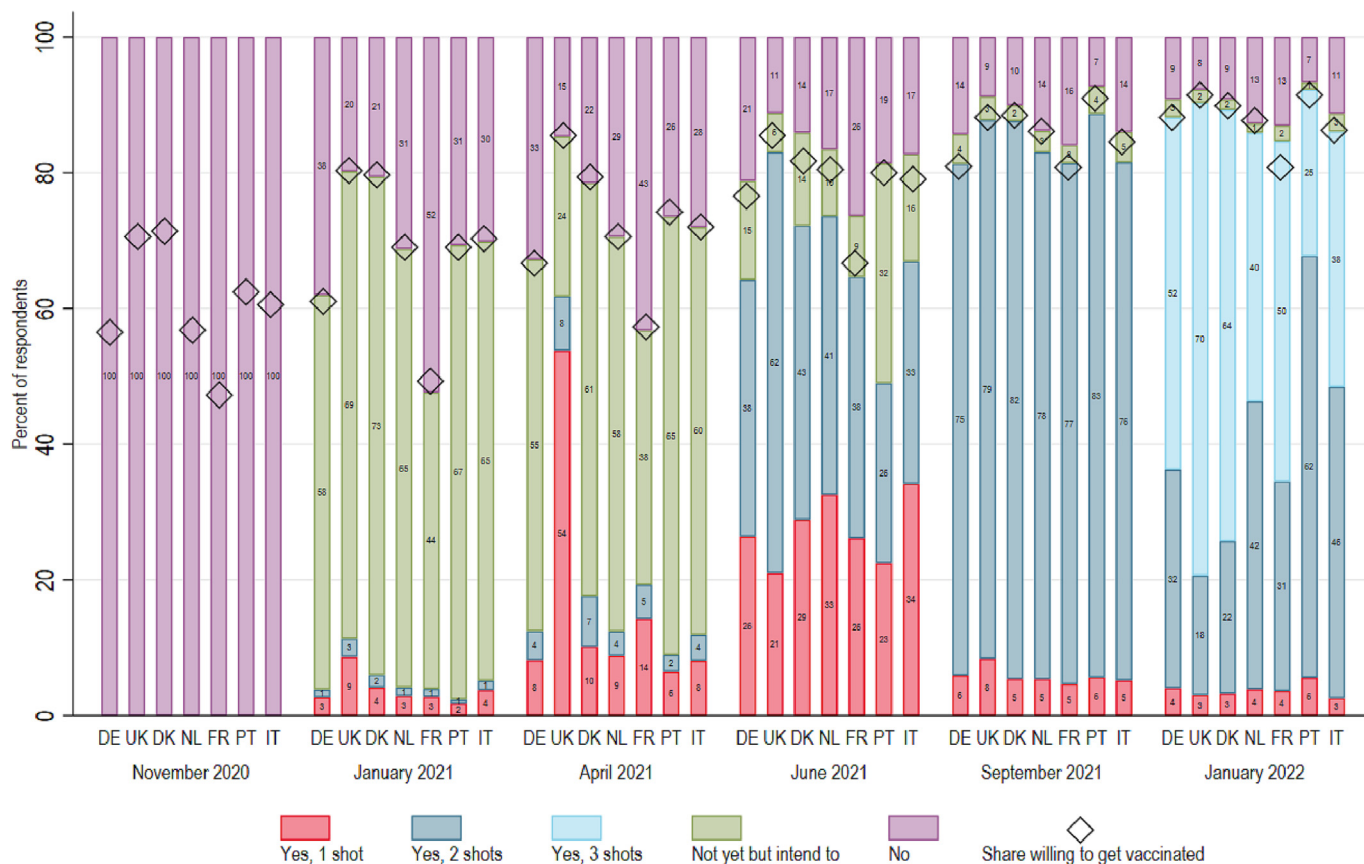


Fig. 5. WTBV and self-reported vaccination status.

health institutions communicate with the public could be considered as a default option instead.

Although completely separating vaccination from government influence may not be entirely realistic, examples from Italy and Portugal demonstrate attempts to disentangle politics from vaccination management. While challenges exist, advocating for depoliticization encourages discussions and actions to minimize undue political influence on public health decision-making. This is particularly relevant in countries with a National Health Service structure, where government involvement is significant, while it may be less pertinent in Social Health Insurance countries, where sickness funds operate with greater independence. Thus, fostering dialogue on depoliticization and minimizing undue political influence can benefit public health outcomes.

Last but not least, the data showed that the extent of following COVID-19 news was another important factor contributing to higher willingness to get vaccinated, which suggests that not only the content of the communication campaigns matters but lowering the cost of following the news for the population is important. Hence, narrowing down to the local level and developing digital strategies accounting for the demographics of the local audience (testing different communication tactics on a continuous basis, using digital platforms and social media to find cost-effective health messaging channels) could be used more actively to build community capacity, increase health literacy, and ensure a better public health emergency preparedness at local levels. Moreover, looking at the timing of inflows and outflows between the WTBV states, as shown in this paper, could be informative for the development of more effective communication campaigns.

An important aspect to highlight is that while all countries participating in our study started vaccination rollout relatively at the

same time and ensured an incremental access to the vaccines, their COVID-19 vaccination policies were heterogeneous throughout the pandemic [31–34]. This heterogeneity stemmed mainly from variations in the prioritization of specific groups for initial and booster vaccinations, the types of vaccines used, approved vaccination groups for a specific vaccination or boosters, vaccine administration protocols, timing of booster vaccinations, and vaccination requirements and mandates (eTable 9). These policy differences may have influenced people’s WTBV. For example, vaccine requirements for leisure activities and travel might have increased an individual’s motivation to get vaccinated, whereas differing safety recommendations for vaccines, such as AstraZeneca and Johnson & Johnson, could have contributed to hesitancy or unwillingness. The lack of coordination and diverging policies among European countries may have fueled public mistrust in governmental and public health institutions, potentially prolonging the persistence of the disease in the population [31]. This emphasizes the crucial need for coordinated and strengthened risk communication efforts between regulatory agencies and policy makers across European countries. It is essential that this communication is transparent, simple, and consistent, with agreed-upon common lines for explaining adverse events.

Finally, our descriptive analysis examining the relationship between the WTBV and self-reported vaccination status indicated a potential correspondence between individuals’ WTBV and their actual vaccination behavior or intentions. This finding added further weight to the hypothesis that hesitancy is a more malleable state open to persuasion, whereas unwillingness tends to be more resistant to change. We also found that while it is important to address and mitigate any negative experiences individuals may have with vaccination, such cases are not the primary driver of vac-

cine hesitancy or unwillingness at a population level. A follow-up study is necessary to investigate the link between the intention to get vaccinated and actual vaccination behavior.

#### 4.3. Limitations

We used stated choice and within the scope of this paper did not investigate if the reported willingness to be vaccinated resulted in a vaccination decision. Stated choice always involves the risk of respondents giving socially acceptable or desirable answers. While this is a limitation, we are confident that the anonymity of our questionnaire minimized the risk of socially desirable answers. While our study does not directly answer the question of whether hesitant individuals eventually choose to vaccinate or not, we believe that by examining the factors influencing willingness to be vaccinated, we contribute to the broader understanding of vaccine acceptance and provide a foundation for future research exploring the transition from vaccine hesitancy to actual vaccination.

We used a three-point scale for the willingness to get vaccinated variable that may have not been able to capture nuances, like a continuous measure of a likelihood of being vaccinated in percentage terms would do. On the other hand, our measure made it simple for respondents to state their willingness, whereas defining degrees of vaccination hesitancy states ex-post is very sensitive to the cut-off points for each category i.e., at which percentage level does hesitancy start and when it can be defined as a refusal.

We only looked at shifts in the willingness to vaccinate that occurred between two consecutive periods, meaning that we did not account for switches that took place between non-consecutive periods or if the respondents missed a wave and re-appeared in a non-consecutive wave. Nevertheless, when reporting transition probabilities, we used available software computational techniques to normalize for missing periods and estimated the Markov transition matrix for the probabilities of switches between the states.

## 5. Conclusions

This study uncovered the dynamic nature of COVID-19 vaccine intentions and its predictors in 7 European countries. The findings provide insights to policymakers for designing more effective communication strategies, particularly targeted at hesitant and unwilling to vaccinate population groups, to increase vaccine uptake for future public health emergencies.

#### Data availability

Data will be made available on request.

#### Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Iryna Sabat reports financial support, article publishing charges, and travel were provided by Horizon 2020 Research and Innovation Programme of the European Union through the Marie Skłodowska-Curie Grant Agreement 721402. Tom Stargardt reports financial support was provided by German Research Foundation (DFG) under grant number 466310982. Tom Stargardt reports financial support, article publishing charges, and travel were provided by Horizon 2020 Research and Innovation Programme of the European Union through the Marie Skłodowska-Curie Grant Agreement 721402. Jonas Schreyögg reports financial support was provided by German Research Foundation (DFG) under grant num-

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**Authors' contributions:** All authors contributed to the manuscript. IS, TS and JS conceptualized the idea and developed the methodology of the study. IS conducted the formal analysis, investigation and data visualizations and wrote the original draft. JE, JS, TS, PPB, WB, SNB and AT provided critical revisions and validation. IS and SNB equally contributed to the design and implementation of the survey with expertise and feedback from PPB, WB, JE, AT, JS and TS. Tom Stargardt and Jonas Schreyögg equally contributed to the study and should be regarded as Senior authors.

Iryna Sabat, Jonas Schreyögg, Tom Stargardt, had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

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## Appendix A. Supplementary data

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