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COVID-19 vaccination, preventive behaviours and pro-social motivation: panel data analysis from Japan

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The COVID-19 vaccine reduces infection risk; even if one contracts COVID-19, the probability of complications such as death or hospitalisation is lower. However, vaccination may prompt people to decrease preventive behaviours, such as staying home, washing hands, and wearing a mask. Therefore, if vaccinated people pursue only self-interest, the vaccine's effect may be lower than expected. However, if vaccinated people are pro-social (motivated toward benefits for the whole society), they might maintain preventive behaviours to reduce the spread of infection. We conducted 26 surveys almost once a month from March 2020 (the early stage of COVID-19) to September 2022 in Japan. By corresponding with identical individuals, we independently constructed the original panel data ($N = 70{,}908$). Based on the data, we identified the timing of the second vaccine shot and compared preventive behaviours before and after vaccination. We investigated whether second-shot vaccination correlated with changes in preventive behaviours. Furthermore, we explored whether the vaccination effect differed between the older and younger groups. We then investigated the effect of pro-social motivation on preventive behaviours. Major findings are as follows: (1) Being vaccinated led people to increase preventive behaviours, such as mask-wearing by 1.04 (95% confidence intervals [Cis]: 0.96–1.11) points, and hand hygiene by 0.34 (95% CIs: 0.30–0.38) points on a 5-point scale. (2) Vaccinated people under 65 are less likely to stay home. (3) People with pro-social motivation to be vaccinated are more likely to maintain prevention than those not so motivated; on a 5-point scale, the difference is 0.08 (95% CIs: 0.01–0.15) points for mask-wearing and 0.05 (95% CIs: 0.001–0.10) points for hand hygiene. After vaccination, the opportunity cost of staying home outweighs its benefits, and people are less inclined to stay at home. This effect is lower in older people who are at a higher risk of serious illness. The opportunity cost of wearing masks and hand hygiene is lower than that of staying home, and the benefit persists after vaccination if people are motivated to maintain these behaviours for others' well-being.

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Introduction

Various preventive behaviours were required during the COVID-19 pandemic, especially in the early stages, because vaccines against COVID-19 had not been developed. Preventive behaviours can be considered a kind of public good that is not sufficiently supplied through market mechanisms in which people pursue self-interest (Cato et al., 2022, 2020). Mitigating the pandemic necessitated the collective action of citizens. However, according to the Peltzman effect, people tend to increase their risky behaviours if safety measures are implemented (Trogen and Caplan, 2021).

Since 2021, vaccines against COVID-19 have been distributed worldwide and have played a vital role in curbing the spread of COVID-19. Newly reported cases have decreased in countries where vaccines have been rapidly adopted (World Health Organization, WHO, 2022). If rational, people tend to engage in risky behaviours when security measures are mandated (Peltzman, 1975). In economic terms, this is considered a moral hazard. An empirical question arises as to how the spread of the vaccine influences preventive behaviours (Zhang et al., 2021a; Si et al., 2021). As a result of the reduction in the risk of COVID-19 infection, risk-taking behaviours increase and preventive behaviours such as staying home, wearing masks, and washing hands change (Zhang et al., 2021b; Hossain et al., 2022). However, some studies show no clear evidence that vaccinated people have decreased preventive behaviours compared to those who have not been vaccinated (Zhang et al., 2021a; Wright et al., 2022).

The influence of vaccination on preventive behaviours may vary according to the type of behaviour (Corea et al., 2022). A study found that, in China, vaccination reduced the frequency of hand hygiene but did not change mask-wearing (Si et al., 2021). This study aimed to explore the mechanisms that prevent vaccinated people from developing preventive behaviours. To this end, we investigated how preventive measures can be pro-socially motivated based on altruism and social solidarity (Cheng et al., 2022).

We investigated whether preventive behaviours changed after vaccination using monthly individual-level panel data. Furthermore, we examined how the influence of vaccination on preventive behaviours differed according to age and pro-social motivation.

Data and methods

Data collection. COVID-19 vaccination was not developed when we initially planned to collect the data. Inevitably, the sampling method was not specifically designed to investigate how COVID-19 vaccination changes preventive behaviours. However, prior to starting the survey, we planned to construct panel data by pursuing individual behavioural changes through repeated surveys. Then, in response to the real situation after the development of COVID-19, we added a question about vaccination.

We commissioned the research company INTAGE, Inc. to conduct an online survey because of their experience and reliability in academic research. The first wave of queries was conducted from 13 March to 16 March 2020, and 4,359 observations were recorded. Participants registered with the INTAGE were recruited for this study. The participation rate was 54.7%. The sampling method was designed to collect representatives of the Japanese adult population in terms of educational background, sex, and residential area. For this purpose, INTAGE recruited participants for a survey of preregistered individuals. However, individuals aged 17 years and below were too young to be registered with INTAGE, and individuals over 78 years of age could not be collected because they were unlikely to use the Internet. Inevitably, the sample population was restricted to 18–78 years, and participants were randomly selected to fill the pre-specified quotas. INTAGE provided monetary incentives to participants upon completion of the study.

Internet surveys were conducted 26 times ('waves') almost every month with identical individuals to construct the panel data. The exceptional period was July-September 2020 when the survey could not be conducted because of a shortage of research funds. We resumed the survey after receiving additional funds in October 2020. Vaccination was implemented in April 2021; therefore, the data cover the periods before and after the implementation of vaccination.

Respondents from the first wave were targeted in subsequent waves to record how some respondents changed their behaviour during the COVID-19 pandemic. From the 12th wave of surveys, we asked about the experience of getting the first and second shots of vaccination. Accordingly, the data allowed us to compare the preventive behaviours of identical individuals against COVID-19 before and after vaccination. During the study period, some identical respondents were dropped from the study sample because some stopped taking the surveys, while others did not take the surveys at all. Furthermore, the sample was restricted to those who were completely vaccinated after obtaining a second shot. Therefore, some respondents who continuously participated in the first wave were excluded from this study's sub-sample. In this way, we compared their behaviours before and after vaccination. Eventually, the number of identical individuals was reduced from 4359 to 3019 and the total number of observations used in this study was 70,979.

Methods. The survey questionnaire contained basic questions about demographics such as birth year, gender, and educational background. These characteristics were observed at different time points. The surveys were conducted 26 times between March 2020 and September 2022. During the study period, conditions such as the spread of infection and policies against COVID-19 changed drastically. Table 1 lists the key variables used in the regression estimations. As outcome variables, the respondents were asked questions concerning preventive behaviours, such as:

'Within a week, to what degree have you practised the following behaviours? Please answer on a scale of 1 (I have not practised this behaviour at all) to 5 (I have completely practised this behaviour).'

(1) Staying home
(2) Mask wearing
(3) Wash my hands thoroughly

The answers to these questions served as proxies for the following variables for preventive behaviours: staying home, frequency of hand hygiene, and degree of wearing masks. Larger values indicate that respondents are more likely to engage in preventive behaviours. Further, the motivation to get a shot of COVID-19 vaccination was asked in the following question: 'Did you get the shot to decrease the spread of COVID-19 infection?'

We also asked about the subjective probability of contracting COVID-19 and their perceptions of the severity of COVID-19. We asked whether they received a second shot of the vaccine because vaccination was effective only after completing the second shot. The latter question was included in the questionnaire from the 12th wave, conducted in May 2021, directly after the vaccine was introduced in Japan. The question was included until the 18th wave in November 2021, when most participants in the sample completed the second shot. The question was then excluded from the questionnaire, starting with the 19th wave of January 2022. In the 12th wave, we also added

Table 1 Definitions of key variables.

Variable	Definition
	Outcome variables
Staying home	How consistent were you at 'not going out of home' in the last week? Please choose among 5 choices. 1 (not consistent at all) to 5 (completely consistent).
Wearing mask	How consistent were you at 'wearing a mask' in the last week? Please choose among 5 choices. 1 (not consistent at all) to 5 (completely consistent).
Hand hygiene	How consistent were you at 'washing your hands' in the last week? Please choose among 5 choices. 1 (not consistent at all) to 5 (completely consistent).
	Confounders (Independent variables)
Vaccine	Did you get the second shot? 1 (Yes) or 0 (No)
Probability covid19	What percentage do you think is the probability of your contracting the novel coronavirus (COVID-19)? 0 to 100 (%)
Severity covid19	How serious do you expect your symptoms to be if you are infected with the novel coronavirus? Choose from 6 choices. 1 (very small influence) to 6 (death)
Deaths	Number of deaths caused by COVID-19 in a residential prefecture at the time of the survey.
Infections	Number of persons infected with COVID-19 in a residential prefecture at the time of the survey.
Ages below 25	Answer 1 if respondents are aged 18–25 at the first wave, otherwise 0
Ages 26–64	Answer 1 if respondents are aged 26–64 at the first wave, otherwise 0
Pro-social	In deciding whether to get the shot of the COVID-19 vaccine, is it important that it prevents the spread of COVID-19? 1 (strongly disagree) to 5 (strongly agree). 'Pro-social' is 1 if a respondent chooses 5; otherwise, 0.

questions about the motivation to get the vaccination. We defined a proxy for 'pro-social' motivation based on the following question:

'In deciding whether to get the shot of the COVID-19 vaccine, is it important that it prevents the spread of COVID-19?'

The question had five choices: 1 (strongly disagree) to 5 (strongly agree).

Most of the respondents chose '5'. Therefore, the proxy dummy, 'Pro-social', is defined as 1 if a respondent chooses 5; otherwise, it is 0. On the basic assumption of classical economics, individualistic persons are motivated to pursue self-interests and do not consider others' interests. Human beings who consider others' interests are out of accordance with this assumption. The spread of COVID-19 depends on the degree that surrounding people were infected with the virus. If persons are motivated to prevent the spread of COVID-19, their personality can be considered prosocial.

We pursued identical respondents from the first-wave survey to the 26th wave for 30 months, although some of the respondents quit the survey. This study aimed to explore how the preventive behaviours of identical persons changed before and after vaccination. Therefore, we limited the sample to those who completed the second shot by the 18th wave and then pursued identical persons until the 26th wave on September 2022. We used panel data containing 3,019 individuals, covering 26 time points from March 2021 to September 2022.

We used a fixed-effects (FE) model regression based on panel data. The FE model is a linear regression model widely used in economics. The estimation result using an FE model is equivalent to the result of a linear regression model with dummies for individuals frequently included in each period (Wooldridge, 2009; Hsiao, 1986; Baltagi, 1995). In this study, 3019 dummies were included to control for individuals' characteristics that did not change during the period, such as gender, educational background, and childhood experience. Hence, 3019 confounders were included, reflecting differences between individuals. Therefore, the estimated results for the time-invariant confounders could not be obtained. Even if various time-variant confounders are included, unobserved individual characteristics cannot be identified. This inevitably results in omitted variable biases (Wooldridge, 2009; Baltagi, 1995). For instance, an increasing trend in the number of newly infected individuals has been observed throughout Japan. This effect is common among all residents of Japan and has changed over time. This can be regarded as a time-fixed effect and can be controlled by including time-period dummies. This study included 25 time-period dummies when one base period was fixed. However, some variables changed not only over time but also between individuals. Examples include proxy variables for preventive behaviours, which are outcome variables, or the number of newly infected persons and deaths due to COVID-19 in residential areas. Furthermore, the timing of obtaining the second vaccine shot changes over time and between individuals; therefore, the dummy for vaccination is included in the estimated function as a confounder.

As explained, we controlled not only for unobservable individual fixed effects but also for unobservable time-fixed effects. This type of FE model is called a two-way error component regression model (Baltagi, 1995). This study focused on the correlation between vaccination and preventive behaviours. The statistical software used in this study was Stata/MP 15.0 multiprocessor (StataCorp, LLC.

The estimated function of an FE model takes the following form:

$$\mathrm{Y_{it}} = \alpha_1 \mathrm{Vaccine_{it}} + \mathrm{X'B} + \mathrm{k_t} + \mathrm{m_i} + \mathrm{u_{it}}$$

where Y_{it} represents the outcome variables for individual i and wave t, respectively. X is vector of various control variables such as 'Probability COVID-19', 'Severity COVID-19', 'Number of people infected with COVID-19,' and 'Number of deaths caused by COVID-19', while B is vector of their coefficient. Time-invariant individual-level fixed effects are represented by m_i. Furthermore, k_t represents the effects of different time points controlled by 25 wave dummies, where the first wave is the reference group. k_t captures the various shocks that occur simultaneously throughout Japan at each time point. Y includes preventive behaviours captured by three proxy variables: *STAYING HOME*, *HAND HYGIENE*, and *WEARING MASK*. These outcome variables are discrete-ordered variables ranging from 1 to 5. Larger values of these variables can be interpreted as indicating that respondents are more likely to exhibit preventive behaviour. As explained in the next subsection, the mean value of the proxy variable for the three preventive behaviours varied widely. Hence, standardised value is calculated and used for FE model estimations. In the same specification, we conduct three separate estimations and the regression parameters are denoted as α. The error term is denoted by u_{it}. A simple FE linear regression model was used in this study.

The key confounder is the vaccination dummy; *VACCINE* is 1 if respondents have completed the second shot of the COVID-19 vaccine; otherwise, 0. People are obliged to get a second shot within a month of the first shot to make the vaccine effective. Hence, in the sample, there was hardly any time lag between the first and second shots because the survey was conducted every month after the vaccine was approved. There were two age groups: young age (AGE_25) and middle working age (AGE_26_64). The senior group was used as the reference group. PRO_SOCIAL is a dummy variable that captures the pro-social motivation to be vaccinated. The mean value of PRO_SOCIAL is 0.86, which shows that 86% of people have pro-social motivation.

To explore how the effect of vaccination differs according to age groups, we incorporate 'Vaccine' interacted with age group dummies such as 'Ages below 25' and 'Ages 26–64';

$$Y_{it} = \beta_1 Vaccine_{it} + \beta_2 Vaccine_{it} \times Ages\,below25_i + \beta_3 Vaccine_{it} \times Ages26-64_i + X'B + k_t + m_i + u_{it}$$

Age group dummies are defined by individual *i*'s age in the first wave and hence, do not change during the study period. The coefficient cannot be calculated because the FE estimation approves its effect. However, interaction terms such as $Vaccine_{it} \times$ Ages below 25_i and $Vaccine_{it} \times$ Ages $26–64_i$ can be calculated. The reference age group was those over 65 years. Interpretation of interaction terms is as follows: For example, β_2, coefficient of $Vaccine_{it} \times$ Ages below 25, is negative if young people below 25 years are less likely to display preventive behaviour than those over 65 years.

Next, we also investigate how the effect of vaccination depends on pro-social characteristics by incorporating 'Vaccine' interaction with 'Pro-social' dummy;

$$Y_{it} = \gamma_1 Vaccine_{it} + \gamma_2 Vaccine_{it} \times Prosocial_i + X'B + k_t + m_i + u_{it}$$

Similar to the interaction term between vaccine and age groups, '$Pro\text{-}social_i$' is asked in the first wave and, therefore, does not vary throughout the studied period. If γ_2, the coefficient of $Vaccine_{it} \times$ $Pro\text{-}social_i$ shows a positive sign, then pro-social people are more likely to exhibit preventive behaviour after vaccination than before vaccination.

Results

Baseline estimations. Table 2 presents the basic statistics for the dataset. The mean values of 'Wearing mask' and 'Hand hygiene' are over 4, which are remarkably higher than that of 'Staying home'. 'Pro-social' is 0.90, which shows that 90% of people have pro-social motivation. In other words, most Japanese people are pro-social and keep wearing masks and washing their hands.

Comparison of preventive behaviours before and after the second-shot vaccination. There was a distinct difference in the mean values between preventive behaviours. Hence, we calculated the standardised values of behaviours as follows:

$$\hat{x}_i = (x_i - \bar{x})/\bar{x},$$

where x_i is individual *i*'s value while $\bar{x}$ is the mean value of all respondents. We calculate the standardised mean values of $\hat{x}_i$. The mean value $\hat{x}_i$ is 0 a full sample is used. Vaccinated people become more (less) likely to display preventive behaviours than before being vaccinated if the mean value $\hat{x}_i$ using a sub-sample of the post-vaccination period, is positive (negative).

Table 2 Basic statistics of variables and characteristics of respondents.

Variable	Mean	Sd	Max	Min	*N*
Staying home	2.86	1.28	5	1	70,908
Wearing mask	4.56	0.87	5	1	70,908
Hand hygiene	4.22	0.89	5	1	70,908
Vaccine	0.56	0.49	1	0	70,908
Probability COVID19	25.7	22.4	100	0	70,908
Severity covid19	3.60	1.14	6	1	70,908
Deaths	56.1	74.3	294	2	70,908
Infections	25,044	52,278	260,912	33	70,908
Ages below 25	0.05	0.22	1	0	70,908
Ages 26–64	0.64	0.47	1	0	70,908
Pro-social	0.90	0.29	1	0	70,908
Household income below 1 million yens	0.03	0.20	1	0	70,908
Household income 1–1.9 million yens	0.07	0.25	1	0	70,908
Household income 2–2.9 million yens	0.13	0.34	1	0	70,908
Household income 3–3.9 million yens	0.16	0.37	1	0	70,908
Household income 4–4.9 million yens	0.15	0.35	1	0	70,908
Household income 5–5.9 million yens	0.11	0.31	1	0	70,908
Household income 6–6.9 million yens	0.09	0.28	1	0	70,908
Household income 7–7.9 million yens	0.07	0.26	1	0	70,908
Household income 8–8.9 million yens	0.04	0.19	1	0	70,908
Household income 9–9.9 million yens	0.05	0.22	1	0	70,908
Household income 10–11.9 million yens	0.04	0.19	1	0	70,908
Household income 12–14.9 million yens	0.03	0.18	1	0	70,908
Household income 15–19.9 million yens	0.02	0.13	1	0	70,908
Household income over 2000 million yens	0.01	0.10	1	0	70,908
Male	0.51	0.50	5	1	70,908
Ages	52.8	15.6	78	18	70,908

Figures 1–3 compare the mean values of $\hat{x}_i$ before and after the second shot of COVID-19 vaccination. Figure 1 shows that the mean values of $\hat{x}_i$ is 0.02 before vaccination and −0.017 after, respectively. The difference was approximately 0.037 before and after vaccination and was statistically significant. Therefore, vaccination reduced stay-home behaviour by 3.7%.

In contrast, Figs. 2 and 3 illustrate that the mean values of $\hat{x}_i$ were negative before and positive after vaccination. The difference in values before and after vaccination was statistically significant. The difference is approximately 0.065 in Fig. 2, showing that vaccinated people become more likely to wear masks by 6.5% than before vaccination. The difference is approximately 0.035 in Fig. 3, showing that vaccinated people become more likely to wash their hands by 3.5% than before vaccination.

To examine the effect of vaccination on preventive behaviours more closely, we see the results of the FE model estimation to control various variables and unobservable individual and time-fixed effects. The coefficient of confounders indicates marginal effects (ME), which are multiplied by 100 to easily interpret the results. We can interpret the ME of 'Vaccination' as the % change in preventive behaviours when compared with before vaccination.

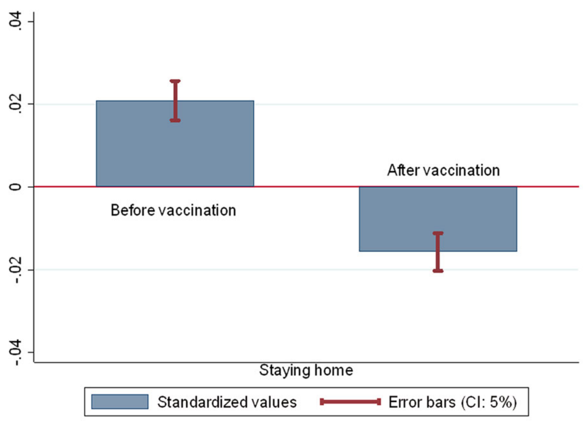

Fig. 1 Staying home behaviour.

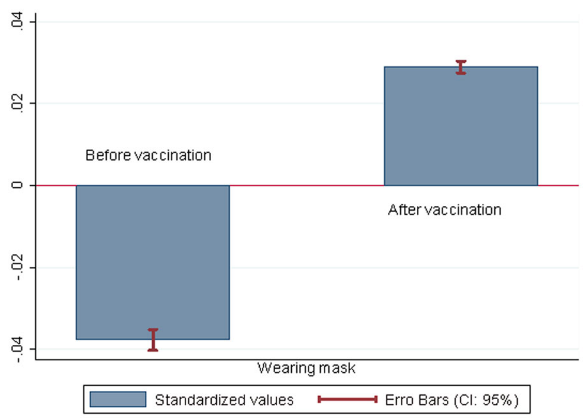

Fig. 2 Mask-wearing behaviour.

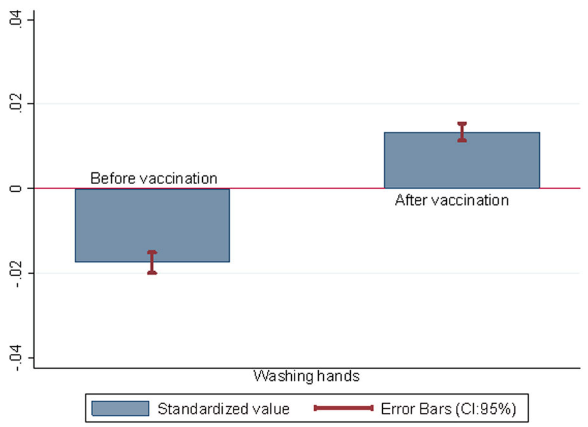

Fig. 3 Hands washing behaviour.

Table 3 presents the estimation results for the baseline FE model. Here, we focus on key variables, although the estimation results of control variables are also presented. The effect of events is controlled by including time point dummies for the surveys. Timepoint dummies are shown as survey periods in Table 3. ‘Vaccine’ shows a positive sign and is statistically significant at the 1% level, except for Column (1), where ‘Stay home’ is the outcome variable. The effects of ‘Vaccine’ are ME 22.7 (95% CI: 21.0–24.3) and ME 8.03 (95% CI: 7.10–8.95) in columns (2) and (3), respectively. Thus, people after vaccination are 22.7% more likely to wear masks than before and 8.0% more likely to wash their hands. People’s behaviours depend on the behaviours of others; hence, they follow social norms (Habersaat et al., 2020; Ohtake, 2022; Sasaki et al., 2022; van der Westhuizen et al., 2020). Peer pressure is stronger for wearing masks than for washing hands because surrounding people in a public place can more easily see whether one wears a mask than whether one washes one’s hands.

We interpreted the significant positive sign of ‘Vaccine’ as follows: The prevalence of vaccination is predicted to reduce preventive behaviour because the risk of infection or deaths due to COVID-19 became lower than before the emergence of the vaccine. In contrast, we found that preventive behaviour improved rather than remaining unchanged before and after vaccination. This is a kind of a paradox. One possible interpretation is that we considered an individual’s reaction to the subjective prediction about others’ behaviour. Individuals predict the prevalence of the vaccine to reduce others’ preventive behaviours. This might in turn increase the risk of COVID-19. Based on the prediction, an individual might improve his/her preventive behaviours.

Estimations with interaction-terms. In panel A, Tables 4 and 5 report the results of the model where the interaction terms are included. Panel B of Tables 4 and 5 show the results using sub-samples divided by age cohorts and the degree of ‘Prosocial’ behaviour to consider the results of Panel A from different angles. As below, we mainly interpret the results of Panel A, where the main results are provided.

The probability and seriousness of contracting COVID-19 differ according to age. COVID-19 is more likely lethal in adults 65 years and older than younger people (Wu and McGoogan, 2020; Koh et al., 2021). Mask-wearing by elderly people is motivated by their self-regarding risk preferences, whereas younger people are motivated by other-regarding concerns (Asri et al., 2021). We explored how the effect of COVID-19 vaccination on preventive behaviours differed between age groups. For this purpose, the interaction terms between ‘Vaccine’ and age groups (‘Ages below 25’ and ‘Ages 26–64’) were included as key confounders. The reference age group was those over 65 years. Panel A of Table 4 presents the results. We find a significant negative sign in ‘Ages below 25’ and ‘Ages 26–64’ in column (1), where ‘Stay home’ is the outcome variable. The effects of ‘Vaccine × Ages below 25’ and ‘Vaccine × Ages 26–64’ are ME −18.8% (95% CI: −23.0 to −14.5) and ME -10.3 (95% CI: −12.3 to −8.3). This means that those under 25 are less likely to stay home by 18.8% than those over 65, while those aged between 26 and 64 are less likely to stay home by 10.3% than those over 65. However, no differences in the effects of vaccination were observed when wearing masks and washing hands.

We investigated how pro-social motivation affects preventive behaviours. The interaction term between ‘Vaccine’ and ‘Pro-social’ was included as the key confounder. Panel A of Table 5 shows the significant positive sign of ‘Vaccine×Pro-social’ where ‘Wearing mask’ and ‘Hand hygiene’ are the outcome variables. The effects of ‘Vaccine × Pro-social’ are ME 2.44 (95% CI: 0.73–4.15) and ME 1.85 (95% CI: 0.39–3.31) on ‘Wearing mask’ and ‘Hand hygiene’, respectively. This suggests that pro-social persons are more likely than non-pro-social persons to wear masks and 2.4% and to wash their hands by 1.9%. Effects of ‘Vaccine’ are ME 20.5 (95% CI: 18.5–22.6) and ME 6.5 (95% CI: 4.9–8.0) on ‘Wearing mask’ and ‘Hand hygiene’, respectively. This is the effect of vaccination on the preventive behaviours of

Table 3 FE model.

	(1) Staying home	(2) Wearing mask	(3) Hand hygiene
Vaccine	−0.34 (−2.62-1.94)	22.71*** (21.05-24.35)	8.03*** (7.10-8.95)
Probability COVID19	0.002 (−0.02-0.002)	0.01 (−0.02-0.02)	0.013*** (0.01-0.02)
Severity COVID19	0.92*** (0.47-1.37)	0.63*** (0.38-0.88)	0.46*** (0.21-0.71)
Deaths	0.31 (−0.67-0.73)	−0.55 (−4.56-3.46)	0.32 (−0.12-0.76)
Infections	0.02*** (0.75-0.03)	0.002 (−0.003-0.007)	−0.002 (−0.007-0.0002)
Household income below 1 million yens		Default	
Household income 1-1.9 million yens	−0.07 (−0.15-0.02)	−0.01 (−0.05-0.02)	0.001 (−0.05-0.05)
Household income 2-2.9 million yens	−0.07 (−0.16-0.01)	0.004 (−0.03-0.04)	0.01 (−0.02-0.05)
Household income 3-3.9 million yens	−0.09 (−0.15-0.02)	0.01 (−0.03-0.05)	0.01 (−0.02-0.06)
Household income 4-4.9 million yens	−0.09* (−0.20-0.01)	0.002 (−0.04-0.04)	0.01 (−0.02-0.05)
Household income 5-5.9 million yens	−0.11** (−0.22 to −0.01)	0.001 (−0.05−0.05)	0.001 (−0.04-0.04)
Household income 6-6.9 million yens	−0.10** (−0.20 to −0.03)	0.02 (−0.02−0.07)	0.02 (−0.02-0.06)
Household income 7-7.9 million yens	−0.11** (−0.22 to −0.01)	0.01 (−0.02−0.06)	0.01 (−0.03-0.05)
Household income 8-8.9 million yens	−0.16*** (−0.28 to −0.04)	0.01 (−0.04−0.07)	0.01 (−0.03-0.06)
Household income 9-9.9 million yens	−0.12** (−0.24 to −0.01)	−0.01 (−0.07-0.05)	0.01 (−0.02-0.06)
Household income 10-11.9 million yens	−0.11 (−0.26-0.03)	−0.01 (−0.06-0.06)	0.02 (−0.02-0.06)
Household income 12−14.9 million yens	−0.06 (−0.23-0.09)	−0.01 (−0.08-0.05)	0.03* (−0.003-0.08)
Household income 15-19.9 million yens	−0.05 (−0.22-0.12)	0.01 (−0.05-0.08)	0.07** (0.01-0.13)
Household income over 2000 million yens	0.01 (−0.19-0.22)	−0.03 (−0.12-0.05)	0.03 (−0.05-0.11)
13-16 Mar 2020		Default	
10-13 Apr 2020	0.05*** (0.03-0.07)	0.01*** (0.008-0.02)	0.01*** (0.002-0.02)
8-11 May 2020	0.17*** (0.14-0.21)	0.10*** (0.08-0.11)	0.04*** (0.03-0.05)
12-15 June 2020	0.30*** (0.27-0.34)	0.19*** (0.18-0.20)	0.07*** (0.06-0.08)
23-28 Oct 2020	0.15*** (0.12-0.17)	0.19*** (0.18-0.20)	0.06*** (0.05-0.07)
4-8 Dec 2020	0.004 (−0.18-0.27)	0.22*** (0.20-0.23)	0.05 (0.04-0.06)
15-19 Jan 2021	0.06*** (0.04-0.07)	0.23*** (0.22-0.24)	0.06*** (0.05-0.07)
17-21 Feb 2021	0.15*** (0.12-0.18)	0.24*** (0.23-0.26)	0.07*** (0.06-0.08)
24-29 Mar 2021	0.14*** (0.11-0.16)	0.25*** (0.23-0.26)	0.07*** (0.06-0.08)
23-36 Apr 2021	0.12*** (0.09-0.14)	0.25*** (0.23-0.26)	0.07*** (0.06-0.08)
28-31 May 2021	0.11*** (0.09-0.13)	0.24*** (0.23-0.26)	0.07*** (0.06-0.8)
25-30 Jun 2021	0.14*** (0.13-0.16)	0.02*** (0.01-0.03)	0.002 (−0.004-0.01)
27 Aug-1 Sep 2021	0.12*** (0.10-0.14)	0.02*** (0.01-0.03)	0.006 (−0.001-0.01)
24-29 Sep 2021	0.12*** (0.10-0.14)	0.01*** (0.01-0.02)	0.004 (−0.001-0.01)
29 Oct-4 Nov 2021	0.15*** (0.14-0.17)	0.02*** (0.01-0.03)	0.01*** (0.01-0.02)
14-19 Jan 2022	0.15*** (0.14-0.17)	0.02*** (0.01-0.03)	0.02*** (0.01-0.03)
25 Feb-2 Mar 2022	0.08*** (0.07-0.09)	0.02*** (0.01-0.03)	0.01*** (0.008-0.02)
15-20 Apr 2022	0.05*** (0.03-0.06)	0.02*** (0.01-0.03)	0.01*** (0.001-0.02)
20-25 May 2022	0.06*** (0.05-0.07)	0.02*** (0.01-0.03)	0.008*** (0.004-0.01)
17-22 Jun 2022	0.09*** (0.07-0.11)	0.02*** (0.01-0.03)	0.005 (−0.005-0.01)
15-20 Jul 2022	0.05*** (0.04-0.06)	0.02*** (0.01-0.03)	0.006* (0.001-0.01)
19-23 Aug 2022	0.02*** (0.01-0.03)	0.01*** (0.006-0.02)	−0.001 (−0.005-0.003)
16-21 Sep 2022	0.004 (−0.01-0.01)	0.003 (−0.01-0.01)	−0.001 (−0.007-0.004)
Individual fixed effects	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes
Controls: New deaths, Newly affected persons,	Yes	Yes	Yes
Adjusted R^2	0.55	0.45	0.62
Observations	70,908	70,908	70,908

Dependent variables are preventive behaviours.
Note: For the convenience of interpretation, the coefficient was multiplied by 10,000 for *Deaths* and *Infections* and by 100 for other variables. Numbers within parentheses are 95% CI. For convenience, the coefficient of the probability of COVID-19 was multiplied by 1000. The model included the number of deaths and infected persons in the residential prefectures in the surveys. However, these results have not been reported. 'Yes' means that variables are included. $^{*}\rho < .10$, $^{**}\rho < .05$, $^{***}\rho < .01$.

Table 4 FE model with interaction terms with age cohorts.

	(1) Staying home	(2) Wearing mask	(3) Hand hygiene
Panel (A) Results using interaction terms			
Vaccine	7.23*** (5.02-9.47)	23.21*** (21.48-24.92)	7.55*** (6.65-8.43)
Vaccine × Ages 26-64	−10.33*** (−12.33-−8.32)	−0.67 (−1.68-0.34)	0.85** (0.09-1.62)
Vaccine × Ages below 25	−18.81*** (−23.08-14.53)	−1.38 (−3.44-0.68)	−1.42 (−3.34-0.49)
Individual fixed effects	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes
Controls: Probability COVID-19, Severity COVID-19, New deaths, Newly affected persons, Household income, Probability COVID-19, Severity COVID-19	Yes	Yes	Yes
Adjusted R^2	0.57	0.47	0.64
Observations	70,908	70,908	70,908
Panel (B) Results using sub-samples			
Vaccine (results sub-sample A age ≥ 65)	13.46*** (8.68-18.24)	24.40*** (22.15-26.88)	7.98*** (6.66-9.29)
Vaccine (results sub-sample A 26 ≤ age ≤ 64)	−5.58*** (−8.66 to −2.51)	22.13*** (20.19-24.7)	8.26*** (7.18-9.33)
Vaccine (results sub-sample A age ≤ 25)	−16.48*** (−25.28 to −7.69)	18.09*** (11.67-24.50)	3.96 (−2.07-9.99)
Individual fixed effects	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes
Controls: Probability COVID-19, Severity COVID-19, New deaths, Newly-affected persons, Household income, Probability COVID-19, Severity COVID-19	Yes	Yes	Yes

Dependent variables are preventive behaviours.
Note: For the convenience of interpretation, the coefficient was multiplied by 100. Numbers within parentheses are 95% CI. All models include control variables equivalent to those in Table 2. 'Yes' means that variables are included. However, these results have not been reported.
**$p < 0.05$, ***$p < 0.01$.

Table 5 FE model with interaction-term 'Pro-social'.

	(1) Stay homes	(2) Wearing mask	(3) Hand hygiene
Panel (A) Results with interaction-terms			
Vaccine	−1.64 (−5.18-1.89)	20.53*** (18.49-22.56)	6.45*** (4.89-8.01)
Vaccine × pro-social	1.68 (−0.76-4.13)	2.44*** (0.73-4.15)	1.85** (0.39-3.31)
Individual fixed effects	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes
Controls: Probability COVID-19, Severity COVID-19, New deaths, Newly affected persons, Household income, Probability COVID-19, Severity COVID-19	Yes	Yes	Yes
Adjusted R^2	0.55	0.45	0.62
Observations	68,030	68,030	68,030
	(1) Staying home	**(2) Wearing a mask**	**(3) Hand hygiene**
Panel (B) Results using sub-samples			
Vaccine (results sub-sample pro-social = 0)	−5.17** (−10.38-0.03)	13.53*** (8.72-18.33)	3.37** (0.32-6.41)
Vaccine (results sub-sample pro-social = 1)	0.33 (−2.05-2.82)	23.77*** (21.96-25.59)	8.64*** (7.62-9.65)
Individual fixed effects	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes
Controls: Probability COVID-19, Severity COVID-19, New deaths, Newly affected persons, Household income, Probability COVID-19, Severity COVID-19	Yes	Yes	Yes

Dependent variables are preventive behaviours.
Note: For the convenience of interpretation, the coefficient was multiplied by 100. Numbers within parentheses are 95% CI. All models include control variables equivalent to those in Table 2. 'Yes' means that variables are included. However, these results have not been reported.
**$p < .05$, ***$p < .01$.

non-pro-social individuals. Considering the results jointly, pro-social persons are 20.5% more likely than non-pro-social persons to wear masks and 6.5% more likely to wash their hands. That is, for pro-social persons, the degree of the effects of vaccination on hand hygiene is more than twice as great as it is for wearing masks. Wearing masks and washing hands are different because the benefit of wearing a mask is more likely to depend on the situation. Wearing masks in open air is only marginally effective in mitigating pandemics (Javid et al., 2021). Pro-social vaccinated persons may consider the cost-benefit ratio of preventive behaviours and, therefore, place more importance on washing hands than wearing masks.

Discussion

Implications. One of the main goals of this study was to explore the preventive behaviours of the COVID-19 vaccination in Japan. Further, we aimed to determine how pro-social motivation leads to differences in preventive behaviours after vaccination.

Peltzman argued that rational individuals engage in risky behaviours if security measures are mandated (Peltzman, 1975). As a whole, people stay home even after being vaccinated. However, there is a variation in staying-home behaviour. As expected, people under 65 years of age were more likely to go out than older people. In contrast, we found that individuals were more likely to wash and wear masks after vaccination. This is in line with the argument that preventive behaviours are considered an investment in public goods to mitigate the spread of COVID-19 (Cato et al., 2020). The motivation for vaccination for 90% of respondents is to mitigate the spread of infection in society. Most people are pro-socially motivated and, therefore, are more likely than others to wash their hands and wear masks after vaccination. However, the 'Stay home' behaviour of pro-social people is not different from that of others.

Staying home differs from wearing masks and washing hands when considering the cost-benefit aspects of preventive behaviours. Staying home leads people to sacrifice their vacation activities in the real world. Using economic terms, sacrifice is the 'opportunity cost' of staying home. They would stay at home if their benefits exceeded their costs. After vaccination, the opportunity cost of staying home was higher than the benefit. Accordingly, younger people were more likely to go out.

Both vaccination and preventive behaviours are considered public goods for coping with pandemics. As a result of vaccination, people tend to leave, which may reduce public goods. To compensate for this, vaccinated pro-social persons are more likely to be motivated to wear masks and wash their hands by considering the benefits to society. Other possible interpretations of the estimation results are related to the cost of vaccination, including the physical and psychological costs of side effects. From an economic viewpoint, the cost of vaccination can be considered the 'sunk cost'—an investment already incurred that cannot be recovered. Due to sunk costs, vaccinated people continue to invest in public goods by strengthening their mask-wearing and hand hygiene behaviours.

Strengths of the study. Previous studies have not shown that individuals reduce preventive behaviours even after vaccination (Zhang et al., 2021a; Wright et al., 2022; Corea et al., 2022). This is contrary to rational behaviour in terms of economics (Peltzman, 1975). However, no study has yet examined the underlying mechanisms. The strength of this study is that it provides evidence that pro-social motivation plays a vital role in enhancing mask-wearing and hand hygiene. This compensated for the decrease in staying home after getting the COVID-19 vaccination. This leads us to argue that people pro-socially make decisions by comparing the costs and benefits of preventive behaviours.

For aged persons, the benefit of staying home was greater than its cost even after being vaccinated. Meanwhile, for younger active persons, the cost of staying home was greater than its benefit, thus reducing their staying home. However, the risk of being infected with COVID-19 would increase if people were more likely to go out. Based on this prediction, people are motivated to engage in other preventive behaviours such as mask-wearing and hand hygiene partly because its cost is far lower than staying home.

Limitations of the study. This study has several limitations. First, we restrict the sample to those who received a second shot during the study period. This allowed us to compare the behaviour of identical individuals before and after vaccination. However, those who were not vaccinated seemed to differ from the respondents included in the sub-sample used for the estimations. Naturally, the results of this study may have been affected by selection bias. While the number of retired individuals has increased drastically in Japan, older people were less able to participate in the survey because of their reduced cognitive ability. Hence, the number of retired people included in the sample was far lower than that in the real setting of Japan, leading to selection bias.

Second, as shown in Table 2, 90% of people are pro-social by definition in this study. As explained in the 'Methods' section, we define 'Pro-social' as respondents who chose '5' among five choices because most of the respondents chose '5'. Therefore, in the definition, respondents who chose '1', '2', '3', and '4' are not 'pro-social' despite the wide variation between them. 'Pro-social' is arbitrarily defined. We obtain similar results to those reported in this study if we use linear variables varying from 1 to 5 as a proxy for 'Pro-social'.[1] However, we did not obtain statistically significant results if 'Pro-social' is defined to choose '4' or '5'.[2] In our interpretation, the number of respondents who chose '4' is far smaller than those who chose '5'. Therefore, there is a significant gap in the characteristics between them.

According to the 2000 Population Census of Japan, foreign residents occupied only 2% of the population (Komatsu, 2022). Japan is a distinctly homogenous society compared with Western countries. This might be one of the reasons people have 'Pro-social' motivation to get a COVID-19 vaccine shot. It should be noted that the results of this study were obtained from a homogenous society. It is unknown whether these results can be generalised to a more heterogeneous society.

We employed an FE model to control for the time-invariant individual characteristics. Furthermore, as confounder variables, time-point dummies are used to control various time events throughout Japan, such as the declaration of the state of emergency and school closure, which influenced individuals' behaviours and mental health (Yamamura and Tsutsui, 2021, 2022). However, there seem to be factors that vary depending on time periods and individuals. Unfortunately, our model cannot control for these factors, which may cause omitted-variable biases.

It is valuable to scrutinise how preventive behaviours changed just after being vaccinated. However, we conducted the survey almost every month. Therefore, we could scrutinise the change of preventive behaviour immediately after getting the first shot only if the timing of the survey was conducted directly after getting 'the first shot'. Further, we did not ask about the exact date of inoculation. Owing to the limitation of data, we could not investigate 'what happened just after vaccination'.

Besides staying home, hand hygiene, and wearing a mask, as the World Health Organisation recommended, self-isolation and maintaining physical distance are also important preventive behaviours. However, we could not collect data on these preventive behaviours owing to the shortage of research funds. People were obliged to get the second shot three weeks after the first shot. In other words, the period between the first and second shots was so short that we could not gather sufficient data from those who got the first shot before getting second one. This study (1) was an Internet survey, (2) only included vaccinated participants, (3) only included those participating in the follow-up survey, and (4) excluded participants aged 78 or older. This resulted in selection bias. Hence, careful attention should be paid when interpreting the estimation results.

Conclusions

In some studies, individuals were unlikely to reduce preventive behaviours even after vaccination (Zhang et al., 2021a; Wright et al., 2022; Corea et al., 2022). This cannot be explained by rational behaviour in terms of economics (Peltzman, 1975). However, to date, no studies have investigated the underlying mechanisms. This study contributes to the understanding of this mechanism by considering pro-social motivation.

On the one hand, vaccinated people under 65 years of age are less likely to stay home than older people. On the other hand, pro-social individuals were more inclined to wash their hands and wear masks after being vaccinated than before getting their second shot. These observations prove that vaccinated people continue to engage in preventive behaviours to invest in public goods to cease the COVID-19 pandemic.

Wearing masks in open air is only marginally effective in mitigating pandemics (Javid et al., 2021); this might result in over-investment in public goods. Owing to data limitations, we could not analyse the situation in which vaccinated people wore masks. It is necessary to determine how and to what extent the preventive behaviours of vaccinated people are effective in mitigating COVID-19.

Data availability
The data sets used or analysed during the current study are provided as supplementary files.

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Notes
1 The results can be available upon request for the corresponding author.
2 The results can be available upon request for the corresponding author.

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Author contributions
EY and FO conceptualised the study and analysed patient data. YT designed the panel survey and collected data. EY wrote the main text and created the tables for the original manuscript. All authors reviewed, edited, and approved the final manuscript. The authors are responsible for the errors.

Competing interests
The authors declare no competing interests.

Ethics approval
This study was conducted with the ex-ante approval of the Ethics Committee of the Graduate School of Economics, Osaka University, and all methods were carried out in accordance with the relevant guidelines and regulations. The Principal Investigator is Prof. Ohtake. The ethics approval number of this study is R021014.

Informed consent
Informed consent for study participation was obtained from all subjects.

Additional information
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