High national acceptance for COVID-19 contact tracing technologies in Taiwan

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Abstract

Taiwan has been a world leader in controlling the spread of SARS-CoV-2 during the COVID-19 pandemic. Recently, the Taiwan Government launched its COVID-19 tracing App the ‘Taiwan Social Distancing App’, however the effectiveness of this tracing App depends on its acceptance and uptake among the general population. We measured acceptance for three hypothetical tracing technologies (telecommunication network tracing, a government App, and the Apple and Google Bluetooth exposure notification system) in four nationally representative Taiwanese samples. Using Bayesian methods, we find high acceptance for all three tracking technologies, with acceptance increasing with the inclusion of additional privacy measures. Modelling revealed acceptance increased with the perceived technology benefits, trust in the providers’ intent, data security and privacy measures, the level of ongoing control, and one’s level of education. Acceptance decreased with data sensitivity perceptions, and perceived low policy compliance by others in the general public. We consider the policy implications of these results for Taiwan during the COVID-19 pandemic and into the future.

Keywords: COVID-19; contact tracking technologies; Taiwan; public health; privacy; privacy calculus

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Taiwan's response to the COVID-19 pandemic, caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus, is considered an international 'Gold Standard' in infectious disease control (W.-K. Wu et al., 2020). Rapid boarder closures, increased mask manufacturing, and immediate home-quarantines for international arrivals monitored by law enforcement officials have been introduced by Taiwan's Central Epidemic Command Centre to stop the virus' spread (Wang et al., 2020). These policy decisions, combined with social behaviours such as social distancing, hand washing, and mask wearing (Milne & Xie, 2020), have proven effective at preventing the spread of SARS-CoV-2, with fewer than 1000 total cases recorded between January 2020 and March 2021 (Roser et al., 2020). However, the asymptomatic and highly infectious nature of SARS-CoV-2 means that outbreaks and deaths are still likely to occur (e.g., Taiwan's fist major outbreak between March - May of 2021 where national cases doubled), and constant vigilance is necessary.

To these ends, the Taiwanese Government has introduced the 'Taiwan Social Distancing App' (Liu, 2021). This App uses the Apple/Google Bluetooth Exposure Notification (EN) System (Google, 2020) to anonymously register nearby phones. However, for this App to be effective it must receive wide public support, and the perceived health benefits of the App must outweigh any perceived risks and harms associated with the tracing App (Laufer & Wolfe, 1977).

Mobile tracing technologies

Mobile tracing technologies use a person's smartphone to alert nearby mobile carriers if they have had contact with someone who identifies as infected with COVID-19 (Oliver et al., 2020). In the case of tracing Apps, a registry of nearby devices are recorded on the user's phone and alerted if the user becomes infected. By contrast, telecommunication systems notify individuals en masse if someone identifies as infected within a designated area. Importantly, these alerts do not require the user to consent to receiving these notifications. In both instances, the choice to identify as infected

through a tracing technology is typically left to the individual. Whether someone chooses to use a tracing technology may depend on their perceived risks and benefits. Figure 1 (top) displays the benefits and risks associated with three common mobile tracing technologies: telecommunication tracing, GPS tracing, and Bluetooth tracing, which we detail below.

Figure 1. COVID-19 mobile tracing technologies, storage options, and the three tracing scenario's surveyed in the current study. A detailed description of each tracing scenario is presented in appendix A.

Telecommunication tracing has already been used as part of Taiwan's 'electronic fence' (Lee, 2020) to monitor individuals in home quarantine, and is effective at monitoring large movements (e.g., driving to work; Trogh et al., 2019) and alerting individuals en masse when an outbreak occurs. However, it has poor spatial resolution, making it ineffective at alerting individual close-contacts who are likely to have contracted the virus. GPS tracing is effective at targeting specific locations (United States Air Force, 2020), however, performs poorly indoors or in built-up areas, making

it an unreliable contact-tracing technology. Bluetooth tracing Apps perform within a limited radius, are obscured by objects such as walls, and register anonymous device identifiers (Samsung, 2018; Biddle, 2020). For these reasons, Bluetooth COVID-19 tracing Apps are favoured by both international Governments and private developers (e.g., the EN System, Taiwan's 'Social Distancing App', Australia's COVIDSafe App, and Germany's CORONA-Warn App; see Google, 2020; Liu, 2021; Australian Government Department of Health, 2020; German Government Department of Health, 2021).

Once a mobile records nearby users, these user registries may be stored in either a centralized or decentralized fashion (Ferretti et al., 2020). Centralized systems store information about a user's contact history on a Government controlled server accessible by health officials, which can be used to supplement manual tracing efforts. Decentralized systems store user's contact registries on the local phone. If an individual identifies as infected, they alert their registered contacts directly, phone-to-phone. Under both systems, exposure alerts require the user to test positive with the virus, and to enter a verification code provided by a health official to avoid false alarms.

Taiwan's new 'Social Distancing App' uses the Apple/Google EN system to register nearby devices, and stores data in a decentralized fashion (Liu, 2021). The government is responsible for the App and individuals are notified if they have been within two meters of an infected individual for more than two minutes over the past 14 days. Data is deleted from the phone after 28 days, and if a contact registry is uploaded to notify users, then this data is deleted from the server after 10-days.

In the current study, we assessed national acceptance for three tracing scenarios - a decentralized Bluetooth app using the EN system (very similar to Taiwan's 'Social Distancing App'), a centralized Government Bluetooth App, and a telecommunication tracing system (similar to Taiwan's electronic fence; see bottom panel, Figure 1).

Technology acceptance

As the success of tracing technologies is dependent upon their perception of acceptability and uptake within the community (particularly given that they generally require the user's consent), it is imperative for governments and policy makers to consider how to maximise their acceptance in order to achieve the most positive public health benefits (Georgieva et al., 2021). Thus, determining what factors predict the acceptance and uptake of a tracing technology, such as Taiwan's 'Social Distancing App', is an important public health issue, and may prove less intuitive than one first assumes. On one hand, a COVID-19 tracing App provides a potential benefit to public health - faster contact tracing and a faster return to unrestricted social mobility when outbreaks occur (Fox et al., 2021). However, tracing Apps may also pose a risk to one's personal data privacy and security (Chan & Saqib, 2021; Andrejevic et al., 2020). This weighing of personal costs against public health benefits has been labelled the 'privacy calculus' (Laufer & Wolfe, 1977; Dienlin & Metzger, 2016), and may be influenced by many and transient factors (see Garrett, White, et al., 2021, for a discussion).

For example, while cases are low, people's internal privacy calculus may place little weight on the risk of infection for themselves and those around them. This in turn may sway them to *not* download an App on the grounds of personal privacy and security. However, these internal metrics may change with an increase in cases, with job-loss or similar impacts caused by the virus, or by discovering someone close to them has become infected. These transient impacts must be accounted for when considering public uptake of a tracing App.

Similarly, one's psychological well-being may play a role in deciding to use a tracing App. Recent research suggests psychological resilience - how well people deal with the adversity of stressful events, tragedy, and trauma - is associated with less concern about the pandemic and lower level of generalized anxiety and depression (Barzilay et al., 2020), which may influence whether tracing Apps are perceived to be necessary or even beneficial to public health. Then again, lower concern about the pandemic may lead people to seek social interactions more frequently, making a

COVID-19 tracing App more beneficial to these individuals.

Finally, one's attitude towards their government and one's neoliberal world-views on how the government should interface with the lives of their citizens, may affect the acceptance and use of COVID-19 mobile tracing technologies (for example, see Lewandowsky et al., 2021). Determining how COVID-19 perceptions and impacts, psychological resilience, governmental and neoliberal world-views influence the privacy calculus governing acceptance of COVID-19 tracing technologies in Taiwan will be the primary aim of this study.

Although acceptance for a mobile tracing App does not necessarily translate to public uptake (c.f., Garrett, White, et al., 2021; Kozyreva et al., 2021; Garrett & Dennis, 2021), determining public support is an important step towards determining what infrastructure and which technologies countries should invest in to combat the spread of COVID-19 and similar virus' (Lewandowsky et al., 2021; Garrett, Wang, et al., 2021). To these ends, the current study investigated the conditions under which three mobile tracing technologies (see bottom of Figure 1) would be deemed acceptable in four nationally representative samples of the Taiwanese population. Samples were collected over the month of April 2020, and combined (as they showed similar characteristics) to investigate which factors were most predictive of public acceptance for mobile tracing technologies in Taiwan.

Method

Participants

Four nationally representative samples of 1,500 participants (6,000 in total, 2,000 per scenario) completed a 15-minute online survey. Surveys were conducted at one-week intervals, starting April 8th 2020 and ending April 29th 2020. Only participants who passed a comprehension check indicating that they had read and understood the contact tracing technology (scenario) presented to them were included in main analyses of this paper. A large number of participants did not pass this check and were excluded, possibly reflecting an English to Chinese translation issue or miscommunication. To

ensure our findings were not adversely affected, modelling was completed with and without participant exclusions and no meaningful differences were observed (see appendix B). Demographics are displayed in Table 1.

Table 1

Demographic information relevant to each sample. Edu: Education. Age presented as the sample mean and standard deviation in years. Final N indicates the analysed sample number after screening for the comprehension check item. Note: ‘Radio’ and ‘Other’ information source options are not displayed as they formed less-than 1% of each sample, and percentages are rounded to the nearest integer if greater than 1.

		Sample 1	Sample 2	Sample 3	Sample 4
Sample	Initial <i>N</i>	1500	1500	1500	1500
	Final <i>N</i>	971	1018	939	897
Mean Age	Years (SD)	41 (12)	40 (12)	41 (12)	41 (12)
Gender (%)	Man	50	50	50	50
	Woman	50	50	50	50
	Other	0	0.2	0.13	0.07
	Unspecified	0	0	0.07	0.27
Education (%)	Pre High School	1	1	1	1
	High School Grad	12	14	14	16
	University Grad	86	85	85	84
Info Source (%)	News Online/Print	59	63	63	64
	Television	26	23	22	19
	Social Media	12	11	13	16
	Friends & Family	2	2	1	1

Design and procedure

Figure 2.A displays the survey design and procedure, and Figure 2.B displays key survey items. Participants provided informed consent before being assessed for their psychological resilience using the 25-item Connor-Davidson resilience (CD-RISC) scale (the CD-RISC scale-items sum to between 0 and 100 with higher values indicating higher resilience, and has previously displayed a high degree of internal consistency, Chronbach’s $\alpha = .89$, and test-retest reliability, Person’s $r = .87$, Connor & Davidson, 2003). Resilience was followed by items assessing participant’s demographics, COVID-19 perceptions and impacts, and government perceptions, before reading one-of-three hypothetical COVID-19 mobile tracing scenarios (telecommunication tracing, a centralized Government App, or the Bluetooth Exposure Notification system;

see Appendix A for these descriptions). Participants then answered questions about the perceived benefits, trust, and potential harms associated with the technology, before indicating if they would ‘accept’ the introduction of this technology? ‘No’ responses were followed by items assessing if attitudes would change i) if data were stored only for six-months (‘Sunset clause’), ii) if there were an opt-out option (telecommunication scenario), and iii) if data were stored locally on the users’ phone (Government App scenario). Finally, attitudes towards immunity passports (not assessed in this paper) and neo-liberal worldviews (attitudes reflecting a belief that the free-market is best at meeting the societal and financial needs of the population) were assessed, before a participant debrief. The exact questions asked to participants are shown in Table 2.

SURVEY DESIGN A		B ITEMS SURVEY KEY	RESILIENCE 1		TRACING SCENARIOS 6	
CONSENT			25-item Connor-Davidson Scale		Telecommunication	
RESILIENCE			DEMOGRAPHICS 2		Government App	
DEMOGRAPHICS 5			Age		Bluetooth EN System	
★ COVID-19 PERCEPTIONS 4			Gender		SCENARIO QUESTIONS 7	
COVID-19 IMPACT 4			Education		Lower Infection Risk	
Government Perceptions 5			Geographic Location		Return to Activities	
TRACING SCENARIO 1 of 3			Information Sources		Reduce Spread	
▲ SCENARIO QUESTIONS 11			COVID-19 PERCEPTIONS 3		Secure Data	
IMMUNITY PASSPORTS* 8			COVID-19 Concern Self		Only Necessary Data	
● WORLDVIEWS 3			COVID-19 Severity Self		Good Intentions	
DEBRIEF			COVID-19 Concern Others		Preserve Privacy	
			COVID-19 Severity Others		Ability to Decline	
			COVID-19 IMPACT 4		Data Sensitivity	
			Job Loss		Perceived Data Risk	
			Days in Lockdown		SCENARIO ACCEPTANCE?	
			COVID-19 Positive Self		W/ SUNSET CLAUSE?	
			COVID-19 Positive Others		W/ OPT-OUT CLAUSE? **	
			International Fatality Estimates*		W/ LOCAL STORAGE OPTION? ***	
			Government Perceptions 5		WORLD VIEW 8	
					Free Market (FM) is Best	
					FM Limited Social Justice	
					Minimal Gov Regulation	

Likert Values

★ 1 = Not at all, 5 = Extremely
▲ 1 = Not at all, 6 = Extremely
● 1 = Str. Disagree, 7 = Str. Agree

* Not examined in this paper.
** Telecommunication scenario only.
*** Government App scenario only.

OR
OR
BENEFIT
TRUST
HARM
IF "NO"

Figure 2. (A) Displays the survey order, the number of items in each item-block (right), and associated Likert response options and values (bottom). (B) Displays a break-down of the key items in this paper. Additional acceptance items are presented in navy-blue for those participants who for the scenario acceptance item responded ‘no’. Technology acceptance was also assessed before the scenario questions, results of which are located in the supplementary materials. Items are displayed in Table 2.

Scenario descriptions. A summary of the three contact tracing scenarios presented to participants is produced below. For the full details of the exact scenarios

Table 2

COVID-19 perceived risk and impact, government perceptions, tracing technology [scenario] questions (benefits, trust and harm), and worldview items. [R]everse scored items.

Item block	Question	Label
Perception 1	How severe do you think novel coronavirus (COVID-19) will be for the general population?	General harm
Perception 2	How harmful would it be for your health if you were to become infected COVID-19?	Personal harm
Perception 3	How concerned are you that you might become infected with COVID-19?	Concern self
Perception 4	How concerned are you that somebody you know might become infected with COVID-19?	Concern others
Impact 1	Have you ever tested positive to COVID-19?	Positive self
Impact 2	Has somebody you know ever tested positive to COVID-19?	Positive other
Impact 3	How many days, if any, have you been in quarantine or self-isolation?	Lockdown days
Impact 4	Have you temporarily or permanently lost your job as a consequence of the COVID-19 pandemic?	Job loss
Gov 1	What percentage of the population do you think is complying with government policies regarding social distancing?	Social Dist.
Gov 2	What percentage of the population do you think is complying with government policies regarding COVID-19?	Compliance
Gov 3	How satisfied are you with the current government's governance?	Governance
Gov 4	How satisfied are you with the current government policies?	Policies
Gov 5	How satisfied are you with the current government's public services?	Services
Benefit 1	How confident are you that the described scenario would reduce your likelihood of contracting COVID-19?	Lower infection risk
Benefit 2	How confident are you that the described scenario would help you resume your normal activities more rapidly?	Resume activity
Benefit 3	How confident are you that the described scenario would reduce the spread of COVID-19?	Reduce spread
Trust 1	How secure is the data that would be collected?	Data security
Trust 2	To what extent is the Government [Apple/Google] only collecting the data necessary to achieve the purposes of the policy?	Data necessary
Trust 3	How much do you trust the Government [Apple/Google] to use the tracking data only to deal with the COVID-19 pandemic?	Trust intentions
Trust 4	How much do you trust the Government [Apple/Google] to be able to ensure the privacy of each individual?	Trust privacy
Harm 1	How difficult is it for people to decline participation?	Difficulty to decline
Harm 2	To what extent do people have ongoing control of their data?	Ongoing control
Harm 3	How sensitive is the data being collected?	Data sensitivity
Harm 4	How serious is the risk of harm from the proposed scenario?	Risk from tracking
Wolrdview 1	Economic systems based on free markets unrestrained by government interference automatically work best to meet human needs.	WV Economy
Wolrdview 2	The free market system may be efficient for resource allocation but it is limited in its capacity to promote social justice.	WV Freemarket [R]
Wolrdview 3	The government should interfere with the lives of citizens as little as possible.	WV Small Gov

presented to participants, see Appendix A.

The telecommunication network tracking scenario described mandatory mobile tracking with no possibility to opt-out. Data would be stored in an encrypted format on a secure server accessible only to the Taiwanese Government who may use the data to

locate people who were violating lockdown orders and enforce these orders with fines and arrests where necessary.

The Government App scenario described a voluntary, centralized COVID-19 tracing App. Data would be stored in an encrypted format on a secure server accessible only to the Taiwanese Government, and would only be used to contact those who might have been exposed to COVID-19.

The Bluetooth scenario described a voluntary, decentralized contact tracing App that would use Bluetooth to help inform people if they have been exposed to others with COVID-19. The Government would not know the identities of these individuals. This scenario was based on Apple and Google’s EN system and closely resembles Taiwan’s current ‘Social Distancing App’.

Data analysis and reporting

Participants were removed from analysis if they did not pass the comprehension check item (total $n = 2175$). Results with these participants included are presented in appendix B.

Likert comparisons. Bayesian ordinal probit regressions were used to directly compare Likert-responses using the MCMCoprobit and HPDinterval functions in R packages MCMCpack Martin et al. (2011) and Coda Plummer et al. (2006), respectively. This method assumes that there are latent normally distributed continuous variables that underlie ordinal responses. These latent variables are then segmented into ordinal Likert responses by $C - 1$ (number of response options $- 1$) thresholds. To set the location of the underlying latent variable and make the model identifiable, the lowest threshold parameter is fixed at zero Albert & Chib (1993) and all other thresholds are estimated. Data samples were modelled together to ensure consistent threshold parameters across the Likert-items (see Bürkner & Vuorre, 2019, for model details), making the items and their 95% highest density intervals directly comparable.

Predictive modelling. Bayesian mixed effects logistic regression was used to predict participants’ acceptance for each COVID-19 contact tracing technology, with

demographics, perceptions and impact of COVID-19, COVID-19 cases and deaths, neoliberal and governmental worldviews, and technology attitudes treated as additive functions of technology acceptance. Random intercept effects were included to account for dependencies introduced by tracing technology, allowing us to focus on acceptance across the three technologies. Likert ratings were treated as numeric data for the purposes of modelling and all non-categorical variables were grand-mean standardised prior to analysis to have a mean of 0 and standard deviation of 1. The four samples were collapsed into a single data set for this analysis. As the reader will see in the results section, sample differences were not meaningful.

Posterior distributions of model parameters were estimated using Hamiltonian Markov Chain Monte Carlo No-U-turn Sampling implemented in Stan via the R package *BRMS* (Bürkner, 2017, 2018). Four chains with 4000 iterations and 2000 burn-ins were used. Non-informative priors were set for the intercept and random effect standard-deviation parameters (both Cauchy distributions centred on 0 and a scale parameter of 2.5), and fixed effects were estimated from weakly informative priors with a laplacian distribution centered on 0 and a scale parameter of 1.

Results

The full results for COVID-19 perceptions, governance and world-view items are included in appendix B and are summarized here. COVID-19 perceptions remained constant across samples, with participants on average reporting as somewhat concerned for themselves, and very concerned about others, and that the virus posed a very severe threat to both themselves and others (appendix, Figure B1). Neoliberal worldview items were similarly constant across samples, with participants somewhat agreeing with neo-liberal freemarket attitudes (Figure B3). Perceptions of the effectiveness of the Government's COVID-19 response decreased with each sample from moderate to a-bit satisfied (Figure B2), and COVID-19 impact measures (days in lockdown, job-loss, and positive cases) were comparable across collection dates (see Table 3). Due to the similarity in samples, data were collapsed and reported as a single data set in the

subsequent results.

Table 3

COVID-19 impact measures and mean psychological resilience as measured by the CD-RISC scale, ranging from 0 - 100 with higher values indicating greater resilience.

	Sample 1	Sample 2	Sample 3	Sample 4
Mean Days in Lockdown (SD)	0.62 (3)	0.62 (3)	0.77 (3)	0.78 (3)
Job Loss (%)	7	9	8	8
Tested Positive (Self) (%)	0.53	0.73	0.8	0.33
Tested Positive (Others) (%)	3	2	3	3
Mean Resilience (SD)	64 (15)	64 (15)	65 (15)	65 (15)

Tracing Technologies

Figure 3 displays the mean ordinal regression posterior distributions and associated likert-style responses for items querying people’s perception of the proposed COVID-19 tracing technologies, with items grouped by perceived benefits, trust, and harm. Individual items are described in Table 2. Perceived benefits for each technology were comparable (categorized as ‘a lot’), with telecommunication tracing being perceived as slightly more capable of lowering the risk of infection. Trust items were similarly comparable, ranging from ‘moderate’ to ‘a lot’, with security perceived as highest for the decentralize Bluetooth App. Harm items differed between technologies - telecommunication tracing was perceived as ‘extremely’ risky, very difficult to decline, as collecting the most sensitive data and being the hardest to maintain ongoing control. The Bluetooth and Government Apps were comparable in their harm assessments.

Acceptance

Figure 4 shows the acceptability and the conditional acceptability (the acceptability of the technologies given certain conditions are met) of each tracing technology. Conditional acceptability shows the subsequent increase in acceptability under a sunset clause (where data is deleted after six-months) and with an opt-out or local storage option. Baseline acceptance was high across all three tracing technologies (67% - 73%), being highest for Bluetooth and then telecommunication tracing.

Figure 3. Ordinal regression mean posterior distributions for items assessing perceptions of each hypothetical tracing technology. Coloured error bars display the 95% highest posterior density interval (HDI), black dots display the posterior mean, black lines display where HDIs do not overlap within an item. Dotted lines depict boundaries separating the latent space into ordinal responses (1 = none to 6 = extremely; 4 = moderate).

Acceptance increased with the additional privacy measures, such as a sunset clause (77% - 82%), local storage option (83%) and opt-out clause (88%).

Regression modelling

Figure 5 displays the posterior estimates from the Bayesian generalized linear mixed effects model of tracing technology acceptance using demographics, COVID-19 perceptions and impact, government perceptions, technology perceptions, psychological resilience, and worldviews as additive factors, with a random intercept for each hypothetical technology (not displayed in the Figure). Error bars display the 95% highest density interval. The posterior estimates and 95% credible intervals of the random technology (scenario) intercepts are displayed alongside all parameter coefficients in the appendix, Table B1. The global intercept had a mean of 0.37 (CI [-0.81:1.34]). Total intercept means (random intercept + global intercept) for each scenario were ordered lowest-to-highest, the Government App ($M = 0.16$, CI

Figure 4. The acceptability and the conditional acceptability of each hypothetical tracing technology. Error bars are 95% Bayesian credible intervals. Highest density intervals *within* each technology do not overlap.

[-0.54:0.95]), telecommunication tracing ($M = 0.43$, CI [-0.23:1.25]), and Bluetooth tracing ($M = 0.44$, CI [-0.22:1.26]). To ensure our participant exclusion criteria (our scenario comprehension check) did not alter our findings, we reran this model without excluding participants based on our comprehension check (see appendix, Figure B4 and Table B2). Findings were nearly identical to those reported in the main text.

Variables that were predictive of technology acceptance - those where the 95% highest density interval does not cross zero - included education (both university and high-school graduates compared to those who did not graduate high-school), and many of the technology perception items. The following variables all had a positive predictive relation with tracing technology acceptance: trust in data privacy and security, trust in the provider's intent, belief the tech will return one to normal activities sooner and will reduce the spread of the virus, and the ability to maintain ongoing control over one's data. To understand the implications of these results, we report results in terms of how their proportionate increase (or decrease) affects the odds of accepting these hypothetical tracing technologies. Belief that the technology will lower the chance one

Figure 5. Bayesian generalized linear mixed effects model of tracing technology acceptance. Bars represent 50% of the parameter distribution centred on the parameter mean, tails display the 95% highest density interval. Opaque variables show instances where the posterior interval does not overlap zero.

will become infected was the most predictive factor, with a 0.57 unit increase in this variable corresponding to a 1.77-times increase in the odds of accepting the introduction of a tracing technology. Psychological resilience and attitudes towards social distancing overlapped zero (by 1% of their 95% CI), bordering our criteria as positive predictive variables.

Predictive variables against the introduction of tracing technologies included a belief that others were not complying with government policies, and perceptions about the sensitivity of the data being collected. Data sensitivity was the most predictive variable against acceptance, with a 0.22 unit increase corresponding to a 1.25-times decrease in the probability of accepting a tracing technology. Posterior estimates for

small-government interference overlapped zero (by 1% of its 95% CI), boarding our criteria as a negative predictor.

Discussion

In April 2020, we asked four representative samples of the Taiwanese public to report on their psychological resilience, perceived risks of and impacts posed by COVID-19, and perceptions of their Government and neoliberal ‘free-market’ world-views, before rating the acceptability of three hypothetical COVID-19 tracing technologies: telecommunication network tracing, a decentralized Bluetooth Exposure Notification-style system backed by Apple and Google, and a centralized government App. Acceptance was high across all three technologies and improved with additional privacy measures. A predictive modelling account of the data showed tracing technology acceptance was predicted by the perceived technology benefits, trust in the providers’ intent, security, and privacy measures, the level of ongoing control, and by one’s level of education. Acceptance was negatively predicted by increased data sensitivity perceptions, and perceived low policy compliance by others in the general public.

Acceptance for each tracing technology was moderate-to-high overall (67% - 73%) and improved with additional privacy measures, such as a sunset clause (up to 82%), local storage option (83%), or opt-out option (88%). Although these results display an overwhelming level of acceptance for any of the proposed tracing technologies, they also showcase participant’s privacy calculus. Acceptance improves with the inclusion of additional privacy measures, suggesting participants are weighing the costs-and-benefits of agreeing to use these technologies. This privacy calculus feeds into how technologies are compared, and whether they are accepted.

Telecommunication tracing was perceived as potentially the most harmful, while both centralized and decentralized Apps were comparable in their harm perceptions. With perceived benefits and trust items comparable across scenarios, it seems the Taiwanese public discriminates between potential tracing technologies based on their harm profiles, and not on their benefits. However, these public health benefits play an

important role in whether individuals are ultimately willing to accept the proposed technology.

Modelling suggests participants' acceptance ratings were based on the technology's benefits, privacy, security, control, and trust in the provider's intent, in addition to the user's education. Non-acceptance was informed by perceptions of poor public compliance and data sensitivity. Knowing someone who has had COVID-19 appears to play a positive role in acceptability decisions, however, was limited in our modelling by the low case-numbers at the time of data collection. This fits with our finding that COVID-19 concerns and perceived virus severity were higher for other's than for one's self.

Our results indicate a potential effect of psychological resilience and social distancing perceptions towards the acceptance of tracing technologies. Similarly, we see perceptions shift away from acceptance with support for small-government interference. These posterior estimates bordered zero and did not pass our arbitrary 95% credible threshold. With national and international attitudes being shaped by the state of the pandemic (e.g., high vs low case numbers, vaccine availability), these variables may provide potential avenues of further study as the pandemic and public attitudes evolve. Interestingly, we observed no evidence that the impact of COVID-19 nor perceptions of government effectiveness (excluding public compliance) influenced technology acceptance.

Our results have a clear real-world application to the newly introduced 'Taiwan Social Distancing App' - an App that closely resembles our Bluetooth scenario or our Government App scenario with a local storage option. Our findings suggest App acceptance would be improved by focusing policy and advertisement on the App's public health benefits (to others, not to one's self), the App's privacy measures, and by highlighting App acceptance and uptake in the community, thereby improving perceptions of public compliance. Focusing on the App's privacy measures (e.g., a data deletion 'sunset' clause and decentralized storage) has the additional benefit of increasing technological transparency, a factor also associated with improved public

health technology uptake (W. Wu et al., 2021). Hopefully, our recommendations may assist the Taiwanese Government in converting the observed high levels of App-acceptance into actual App-uptake - an issue affecting countries that have similarly introduced COVID-19 tracing Apps with high levels of technology acceptance (e.g., Germany and Australia; Kozyreva et al., 2021; Garrett, White, et al., 2021).

The current study had several notable limitations, namely that we only assessed a limited set of tracing technologies and that our survey duration was limited to a short window of the pandemic timeline. These limitations impact the generalisability of our results, making it difficult to infer about the acceptance of other potential tracing technologies or how attitudes will shift with the changing nature of the pandemic. However, this work provides a clear point of reference for national attitudes towards Taiwan's real-world policy choice, the 'Social Distancing App'. This work is further strengthened by extending existing research in Taiwan (Garrett, Wang, et al., 2021) and forming part of a wider international investigation underway in Australia (Garrett, White, et al., 2021), Germany (Kozyreva et al., 2021), the United Kingdom Lewandowsky et al. (2021), the United States of America, Hungary, Switzerland, Italy, Japan, and Spain (see preliminary work at <https://stephanlewandowsky.github.io/UKsocialLicence>).

With vaccine roll-outs delayed, and new COVID-19 variants being discovered, the COVID-19 pandemic continues to pose a public health and economic threat to countries around the world. Through a series of representative Taiwanese surveys, our study found acceptance for three tracing technologies - a government App, telecommunication network tracking, and the Apple/Google Bluetooth exposure notification system - to be very high among the Taiwanese general public. Our findings provide clear policy suggestions to assist public uptake of Taiwan's 'Social Distancing App'. These results may also prove informative for other countries seeking technological solutions that allow economies to reopen without inadvertently reigniting the pandemic.

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Appendix A

Scenario Descriptions

The telecommunication network tracking scenario was described as:

“The COVID-19 pandemic has rapidly become a worldwide threat. Containing the virus’ spread is essential to minimize the impact on the healthcare system, the economy, and save many lives. The Taiwanese Government might consider using phone tracking data supplied by telecommunication companies to identify and contact those who may have been exposed to people with COVID-19. This would help reduce community spread by identifying those most at risk and allowing health services to be appropriately targeted. All people using a mobile phone would be included in the project, with no possibility to opt-out. Data would be stored in an encrypted format on a secure server accessible only to the Taiwanese Government who may use the data to locate people who were violating lockdown orders and enforce them with fines and arrests where necessary. Data would also be used to inform the appropriate public health response and to contact those who might have been exposed to COVID-19, and individual quarantine orders could be made on the basis of this data.”

The government App scenario was described as:

“The COVID-19 pandemic has rapidly become a worldwide threat. Containing the virus’ spread is essential to minimize the impact on the healthcare system, the economy, and save many lives. The Taiwanese Government might consider using smartphone tracking data to identify and contact those who may have been exposed to people with COVID-19. This would help reduce community spread by identifying those most at risk and allowing health services to be appropriately targeted. Only people that downloaded a government App and agreed to be tracked and contacted would be included in the project. The more people that download and use this App the more effectively the Government would be able to contain the spread of COVID-19. Data would be stored in an encrypted format on a secure server accessible only to the Taiwanese Government. Data would only be used to contact those who might have been exposed to COVID-19.

And the Bluetooth (Apple and Google EN system) scenario was described as:

“The COVID-19 pandemic has rapidly become a worldwide threat. Containing the virus’ spread is essential to minimize the impact on the healthcare system,

the economy, and save many lives. Apple and Google have proposed adding a contact tracing capability to existing smartphones to help inform people if they have been exposed to others with COVID-19. This would help reduce community spread of COVID-19 by allowing people to voluntarily self-isolate. When two people are near each other, their phones would connect via Bluetooth. If a person is later identified as being infected, the people they have been in close proximity to are then notified without the government knowing who they are. The use of this contact tracing capability would be completely voluntary. People who are notified would not be informed who had tested positive.”

Appendix B

Modelling

Ordinal regression of Likert-scales

Figure B1 displays the mean ordinal regression posterior distributions and associated likert-style responses for items querying people's perception of COVID-19 severity and concern. Items are described in Table 2 of the main text.

Figure B1. Ordinal regression mean posterior distributions for items assessing the perceived risk from COVID-19 in each sample. Coloured error bars display the 95% highest posterior density interval. Dotted lines depict boundaries separating the latent space into ordinal responses (1 = none to 5 = extremely).

Figure B2. Ordinal regression mean posterior distributions for items assessing Government perceptions in each sample. Coloured error bars display the 95% highest posterior density interval. Dotted lines depict boundaries separating the latent space into ordinal responses (1 = none to 6 = extremely).

Figure B3. Ordinal regression mean posterior distributions for items assessing worldviews in each sample. Coloured error bars display the 95% highest posterior density interval. Dotted lines depict boundaries separating the latent space into ordinal responses (1 = none to 7 = extremely).

Bayesian generalized linear mixed effects modelling presented in the main text

Table B1

Output of the Bayesian generalized linear mixed effects model presented in the results of the main text (with participant exclusions due to the scenario comprehension check).

	Mean Est.	SD	95% CI (Low)	95% CI (High)
Intercept	0.31	0.56	-0.81	1.34
Age	0.04	0.05	-0.06	0.14
Gender Woman	-0.05	0.09	-0.24	0.13
Education Highschool Graduate	1.03	0.45	0.15	1.94
Education University Graduate	0.94	0.44	0.09	1.83
COVID Positive Other	0.63	0.36	-0.03	1.35
COVID Lost Job	-0.05	0.17	-0.39	0.28
Gov Governance	-0.07	0.1	-0.27	0.12
Gov Policies	0.02	0.1	-0.18	0.23
Gov Services	0.06	0.07	-0.09	0.2
COVID Severity Self	0.08	0.06	-0.04	0.19
COVID Severity Other	0.02	0.06	-0.1	0.13
COVID Concern Self	0.02	0.07	-0.13	0.16
COVID Concern Other	0.06	0.07	-0.08	0.21
COVID Comply Percent	-0.1	0.05	-0.19	0
Social Distancing	0.09	0.05	-0.01	0.19
Tech Reduce Likelihood	0.57	0.09	0.4	0.74
Tech Return Activity	0.23	0.09	0.04	0.41
Tech Reduce Spread	0.24	0.09	0.06	0.41
Tech Ease To Decline	-0.05	0.05	-0.14	0.05
Tech TrustNecessary Data	0.12	0.07	-0.01	0.26
Tech Sensitive Data	-0.22	0.06	-0.33	-0.1
Tech Risk	0.07	0.06	-0.04	0.19
Tech Trust Intention	0.24	0.08	0.08	0.41
Tech Trust Privacy	0.27	0.08	0.1	0.43
Tech Trust Security	0.2	0.07	0.06	0.33
Tech Ongoing Control	0.33	0.06	0.21	0.44
WorldView Economy	0.03	0.05	-0.08	0.13
WorldView Freemarket	0.07	0.05	-0.02	0.17
WorldView Smallgov	-0.09	0.05	-0.19	0.01
Resilience	0.09	0.05	-0.01	0.19
Scenario Intercept (SD)	0.47	0.56	0.06	1.94
Rand Int. Telecommunication	0.12	0.37	-0.54	0.94
Rand Int. Bluetooth	0.13	0.37	-0.53	0.95
Rand Int. Gov App	-0.15	0.36	-0.85	0.64
Log Prob	-1552.26	4.44	-1562	-1544.6

Bayesian generalized linear mixed effects modelling: Without participant exclusions

Results are identical with and without participant exclusions based upon the scenario comprehension check, except that the model without exclusions shows an effect of small governmental neoliberal worldviews.

Figure B4. Bayesian generalized linear mixed effects model of tracing technology acceptance with no participant exclusions. Bars represent 50% of the parameter distribution centred on the parameter mean, tails display the 95% highest density interval. Opaque variables show instances where the posterior interval does not overlap zero.

Table B2

Output of the Bayesian generalized linear mixed effects model without any participant exclusions due to the scenario comprehension check.

	Mean Est.	SD	95% CI (Low)	95% CI (High)
Intercept	0.53	0.41	-0.28	1.29
Age	0.04	0.04	-0.04	0.12
Gender Woman	-0.07	0.07	-0.21	0.07
Education Highschool Graduate	0.69	0.33	0.04	1.34
Education University Graduate	0.67	0.32	0.04	1.31
COVID Positive Other	0.31	0.25	-0.17	0.83
COVID Lost Job	0.09	0.14	-0.17	0.36
Gov Governance	-0.1	0.08	-0.26	0.05
Gov Policies	0.11	0.08	-0.05	0.27
Gov Services	-0.03	0.06	-0.14	0.09
COVID Severity Self	0.08	0.05	-0.01	0.17
COVID Severity Other	0	0.05	-0.09	0.09
COVID Concern Self	0	0.06	-0.11	0.11
COVID Concern Other	0.09	0.06	-0.02	0.19
COVID Comply Percent	-0.07	0.04	-0.14	0
Social Distancing	0.06	0.04	-0.02	0.13
Tech Reduce Likelihood	0.44	0.07	0.31	0.57
Tech Return Activity	0.27	0.07	0.13	0.41
Tech Reduce Spread	0.28	0.07	0.15	0.41
Tech Ease To Decline	-0.06	0.04	-0.13	0.01
Tech Trust Necessary Data	0.08	0.05	-0.01	0.18
Tech Sensitive Data	-0.2	0.04	-0.28	-0.11
Tech Risk	0.07	0.05	-0.02	0.16
Tech Trust Intention	0.25	0.06	0.13	0.38
Tech Trust Privacy	0.25	0.06	0.13	0.38
Tech Trust Security	0.14	0.05	0.03	0.24
Tech Ongoing Control	0.32	0.05	0.23	0.42
WorldView Economy	0.04	0.04	-0.04	0.12
WorldView Freemarket	0.06	0.04	-0.02	0.14
WorldView Smallgov	-0.14	0.04	-0.22	-0.05
Resilience	0.08	0.04	0	0.15
Scenario Intercept (SD)	0.33	0.44	0.03	1.49
Rand Int. Telecommunication	0.07	0.27	-0.41	0.64
Rand Int. Bluetooth	0.07	0.26	-0.41	0.65
Rand Int. Gov App	-0.1	0.26	-0.61	0.44
Log Prob	-2509.38	4.47	-2519.11	-2501.67