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The role of uncertainty and affect in decision-making on the adoption of AI-based contact-tracing technology during the COVID-19 pandemic

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Abstract

Objective: This study explores how negative affect, perceived net equity, and uncertainty influence the public's privacy decision-making regarding the adoption of contact-tracing technology based on artificial intelligence (AI) during the COVID-19 pandemic.

Methods: Four hundred and eighteen adults in the US participated in the study via Amazon Mechanical Turk in August 2020. Statistical analyses were performed using the PROCESS macro. Indirect effects and their significance were estimated using bias-corrected bootstrap confidence intervals (CIs) with resampling set to $n = 5000$.

Results: Perceived net equity was positively associated with low levels of perceived uncertainty regarding a COVID-19 contact-tracing application and intention to adopt it. Low levels of perceived uncertainty were positively associated with intentions to adopt such an application, thereby suggesting that a perceived level of uncertainty mediates the association between perceived net equity and adoption intentions. Anxieties regarding AI technology and COVID-19 risks both moderate the associations among perceived net equity, perceived level of uncertainty, and intentions to adopt the contact-tracing technology.

Conclusions: Our findings highlight how the differing sources of emotion influence the associations among rational judgment, perceptions, and decision-making about new contact-tracing technology. Overall, the results suggest that both rational judgments and affective reactions to risks are important influencers of individuals' perceptions and privacy-related decision-making regarding a new health technology during the pandemic.

Keywords

COVID-19, contact tracing, AI technology, uncertainty reduction theory, online privacy management, appraisal theory

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Since the World Health Organization's[1] declaration on March 11, 2020, the world has been amid a global pandemic. This pandemic has disrupted people's lives by its rapid spread, high fatality rate, strain on healthcare systems, and disastrous economic impact.[2] To assess and control the spread of COVID-19, many countries are attempting to utilize a number of technologies and support the global war on the disease.[3] As one of the prominent technologies, contact tracing refers to "the practice of mapping out who an infected person has been in contact with to minimize disease spread" (p. 2).[4] Although contact tracing has been used to limit the spread of various infectious diseases (e.g., Ebola and HIV/AIDS) for several decades,[5,6] artificial intelligence (AI) and machine learning have recently been added to newer *digital* contact-tracing technologies that are more accurate

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and rapid.[7] As of 2020, governments in at least 25 countries and several technology companies have deployed or planned to develop contact-tracing applications to assist in containing the virus.[4,8]

However, with the advent of new contact-tracing technology during the pandemic, privacy concerns have been exacerbated because these technologies depend on the collection and sharing of massive amounts of private data.[8–12] Privacy-related decision-making involves complicated contexts in which ambiguity and uncertainty play a significant role.[13] Therefore, individuals will likely be motivated to reduce uncertainty based on knowledge or information and make better decisions regarding the adoption of contact-tracing technology.[14,15] A cost–benefit analysis of the possible outcomes may function as explanatory knowledge and contribute to uncertainty reduction and increased intentions to adopt contact-tracing technologies.[16–18] However, previous literature suggests that emotions significantly influence decision-making processes.[19,20] Emotions are aroused by cognitive appraisals of events[21,22] and guide subsequent judgment and decision-making.[23] This overall process can apply to the context of the COVID-19 pandemic and digital contact-tracing technologies.

To identify both affect- and cognition-based factors that influence the public's online privacy decision-making during the COVID-19 pandemic, we explored the role of negative affect (i.e., anxieties over COVID-19 and AI technologies), perceived net equity, and perceived levels of uncertainty (i.e., uncertainty reduction) in individuals' decision-making about the adoption of AI-based contact-tracing technology in the context of privacy management. We also compared how two different types of negative affect regarding AI technology (i.e., remedy) and disease (i.e., risk) have similar or different moderation effects within the model in which perceived levels of uncertainty mediate the association between perceived net equity and intentions to adopt AI-based COVID-19 contact-tracing technology.

Literature review

Uncertainty about privacy management and technology adoption decisions

Previous research has demonstrated that machine learning and AI (i.e., machines performing tasks that require human intelligence) are effective in increasing the quality of contact tracing.[7] As an AI-based method, digital contact tracing can monitor the spread of COVID-19 and discover new hotspots through precise and efficient data collection.[24–26] Moreover, as a strategy for personalized risk assessment, digital contact tracing can determine proximity between an infected person and a user and provide a quantifiable individual risk based on the distance and the duration of interactions, self-reported comorbidities, and relevant demographics.[27,28] After the WHO's pandemic declaration in March 2020, several technology companies, including Google and Apple, announced plans to develop smartphone-based contact tracing to help contain the COVID-19 pandemic.[4] Despite their usefulness, risks related to privacy infringements and surveillance have been widely discussed in recent studies.[10–12,29–34] Although digital contact tracing based on smartphone applications has been endorsed by many governments and organizations across the world to help limit the spread of COVID-19,[26,30,31] public concerns regarding privacy intrusions (e.g., giving away one's movement and medical information) have hindered the wider adoption of contact-tracing technologies in many countries.[9]

Privacy-related decision-making involves complex contexts in which incomplete risk information, ambiguity, and uncertainty play significant roles.[13] According to Knight's economic model of risk and uncertainty,[35] an individual's decision-making regarding privacy is partly influenced by unknown outcomes (i.e., uncertainty) and unknown probabilities over outcomes (i.e., ambiguity). Although people often prefer to be informed about uncertainties, they dislike making decisions when the probabilities are uncertain or unknown.[36,37] Therefore, individuals' perceptions of uncertainty can negatively affect or postpone their decision-making.[38,39] Similarly, in the context of our study, it is possible that a participant's perceived uncertainty regarding the risks and benefits of using contact-tracing technology may decrease their intentions to adopt the technology.

As people are ambiguity averse and their intolerance of ambiguity generates negative feelings or emotions,[36,40] they try to reduce uncertainty before making a decision. According to uncertainty reduction theory (URT),[41] which explains the development of initial face-to-face relationships and the formation of initial impressions, to be a competent agent in one's environment, individuals are inherently motivated to reduce uncertainty by gathering information to make better plans and achieve goals during and through communication.[15] URT posits that perceived uncertainty between two communicating parties is related to predicting the other communicating party's future behaviors as well as available alternatives based on existing information (e.g., past behaviors).[42] In this way, uncertainty reduction helps people develop personal liking or favorable impressions of the communicating parties.[41] Although URT has often been used to explain initial relationships in the context of face-to-face communication, uncertainty reduction as a goal-driven process can apply to various contexts where the communicating parties can potentially influence their outcomes (Berger, 1987).[43] URT has been applied to many research studies conducted in the context of social media interactions (e.g., online dating, networking)[44,45] as well as human–computer interactions (e.g., uncertainty about information on a website or decisions governed by

AI).[46,47] In this study, we focused on individuals' uncertainty about the benefits and risks of AI-based digital contract-tracing applications.

Since people are intolerant of uncertainty, which may negatively affect their decision-making,[36,37,39] it is necessary to contemplate what can reduce uncertainty and increase people's intentions to adopt new contact-tracing technologies. Petronio's communication privacy management (CPM) theory[48,49] explains that individuals manage private information by considering the benefits and privacy risks of disclosure when deciding whether to share private information with others. Information disclosure is often decided by individuals' assessments of both the privacy protection offered (i.e., high protection) and the potential privacy risks (i.e., low risk).[48,50] Similarly, the majority of research on privacy decision-making is based on a tradition of a cost–benefit analysis that compares possible outcomes with alternatives.[16,18,51] This fundamental process also applies to the adoption of contact-tracing technologies that are based upon the public sharing of private health information. According to a study conducted in the US, the amount of individual benefit and the degree of privacy risk have played an important role in Americans' willingness to install a COVID-19 contact-tracing application.[52] Similar results were found in studies conducted in other countries, such as Australia, India, and various European countries.[29,31–34] This suggests that achieving a balance between privacy and health data acquisition is one of the most urgent issues in the public adoption of contact tracing for technology-assisted health promotion.

According to the equity-implementation model (EIM),[53] individuals evaluate the change caused by a new technology based on perceived net equity, which refers to the difference between the costs and benefits associated with a new technology.[54] The perceived net equity of adopting contact-tracing technology can reflect a comparison between the perceived benefits (e.g., a reduced danger of COVID-19 spread) and perceived risks (e.g., privacy concerns) of adopting contact-tracing technologies to contain the spread of COVID-19. Previous literature suggests that individuals evaluate relative advantages at different stages of decision-making to make the best choice,[55] and this assessment also affects their privacy decision-making, such as health information sharing.[54] Moreover, several studies have found that individuals' evaluations of risk and benefits significantly influence their adoption of COVID-19 contact-tracing technologies.[29,32,33] This study explored individuals' decision-making on the adoption of contact-tracing technologies based on perceived net equity. In this context, perceived net equity can be understood as the outcome of a cost-benefit analysis that compares potential outcomes with alternatives based on the privacy risks and the individual and social benefits of adopting contact-tracing technologies.

Since explanatory knowledge is the most direct way to reduce uncertainty,[14] it is expected that perceived net equity reduces perceived uncertainty regarding privacy risks and benefits and, as a result, increases individuals' intentions to adopt a new technology. However, if net inequity is perceived, individuals will likely resist the adoption of new technology.[56] In other words, individuals will be more likely to intend to adopt a contact-tracing technology if they perceive a net advantage of adoption (e.g., quickly containing the spread of the disease). However, if individuals perceive greater privacy risks than benefits, this would negatively influence their intention to adopt the technology.

Thus, the following hypotheses were formulated:

H1: Perceived net equity will be positively associated with a low level of uncertainty (i.e., uncertainty reduction) regarding the benefits and risks of a COVID-19 contact-tracing application.

H2: Perceived net equity will be positively associated with intentions to adopt a COVID-19 contact-tracing application.

H3: A low level of uncertainty (i.e., uncertainty reduction) will be positively associated with intentions to adopt a COVID-19 contact-tracing application.

Negative affect and decision-making about privacy management in an uncertain situation

Drawing on URT[15,41] and EIM,[53] we proposed a conceptual model relating perceived net equity regarding the privacy risks and benefits of using COVID-19 contact-tracing technologies with uncertainty reduction and intentions to adopt contact-tracing applications. As discussed previously, individuals will be able to reduce their uncertainty about the risks and benefits of using COVID-19 contact-tracing technologies and have an increased intention to adopt them if the technology offers a relative advantage (i.e., net equity) over the potential risks of privacy invasion. We further extend the current model based on URT[15,41] and EIM[53] to investigate the role of negative affect (i.e., anxiety about COVID-19 and AI technology) in the dynamics among perceived net equity, uncertainty reduction, and decision-making about the contact-tracing technologies (see Figure 1).

Emotions have been shown to significantly influence decision-making processes.[19,20] While the majority of research on privacy decision-making has focused on a cost–benefit analysis of potential outcomes, social psychologists have also applied heuristics to understand human decision-making. Cognitive emotion theories (or appraisal

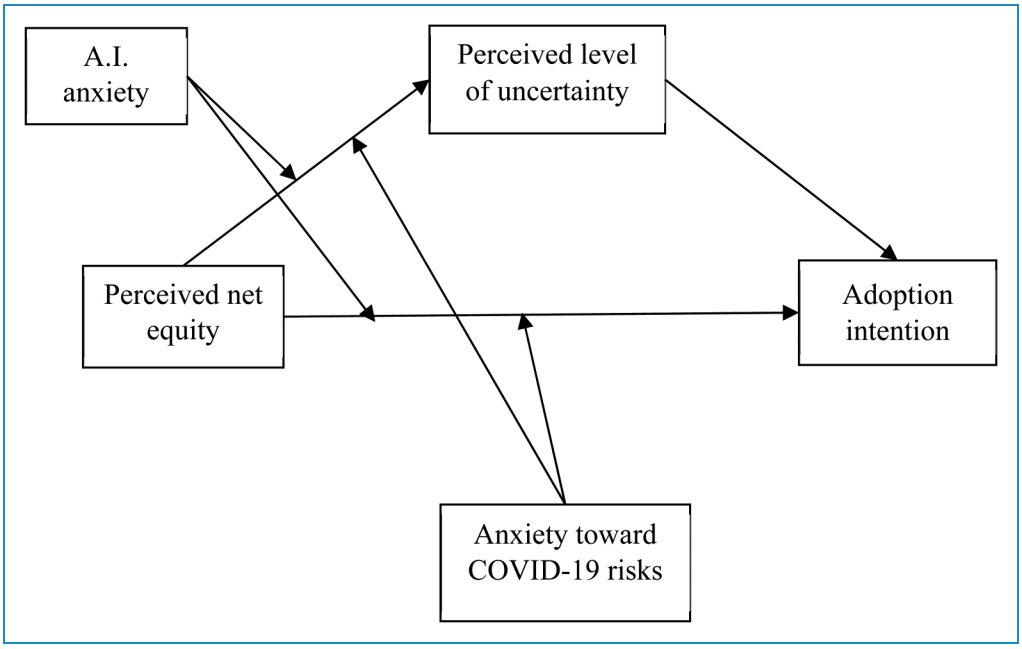

Figure 1. The model for Testing Mediation and Moderation Effects.

theory)[21,22] suggest that emotions are aroused by cognitive evaluations or appraisals of events, and the resulting discrete emotions are based on the patterns of appraisals. Discrete emotions trigger physiological, behavioral, and communicative responses that enable individuals to manage encountered problems quickly.[57,58] As the affect-as-information model suggests, emotional feelings, as well as emotion-related processes, serve as affective feedback that guides subsequent cognition, decision-making, and behavior, regardless of the original cause of the emotion.[23]

Emotion-related cognition interferes with existing cognitive processes and affects attention, memory, and judgment.[59,60] In particular, negative emotions are known to influence risk perceptions regardless of the relevance of the judgment source.[61] According to Johnson and Tversky's classic study,[62] reading a newspaper article on human-related traumatic events (e.g., leukemia, fire, and homicide) and subsequent negative emotional reactions to the events influenced people's general risk estimates, regardless of the relevance between the event in the article and the risk being estimated. Subsequent literature based on the appraisal framework also suggests that when individuals face uncertain and/or uncontrollable events, they experience negative emotions (e.g., anxiety and fear) that may affect their risk perceptions and cognition.[63,64] This fundamental process can be equally applied to understanding the puzzle of negative affect and anxieties in the context of COVID-19 and contact-tracing technologies.

In the context of the present study, individuals' sources of negative emotions can be disease (i.e., COVID-19), AI technology (i.e., digital contact-tracing technology), or both. Although people may conduct a cost–benefit analysis of the possible outcomes of adopting contact-tracing technologies and make final decisions based on the perceived net equity, as discussed above, emotions are capable of altering perceptions and physiology and, finally, influencing individuals' decision-making. Similarly, perceived uncertainty regarding the risks and benefits of using contact-tracing technologies might not be free from the upsurge of emotions caused by the following two risk-related events: COVID-19 and the adoption of digital contact-tracing applications.

The characteristics of the COVID-19 pandemic include uncertainty and uncontrollability, which are related to negative emotions.[64,65] In particular, COVID-19-related threats are uncertain and mysterious, triggering much more anxiety than other general negative emotions, such as fear.[30,66] For example, during the pandemic, there have been many infected people who were asymptomatic. Thus, it was impossible to know if people were infected or not, which makes it more difficult to calculate the fatality rate accurately.[66] Individuals' intolerance to uncertainty maximizes the effect of the unknown on anxiety because fear of the unknown is a core component of anxiety.[67–69] As previous literature suggests, an individual's cognitive perceptions and decision-making can be affected by emotional feelings and processes caused by COVID-19. In fact, according to recent literature on COVID-19, individuals' anxiety about COVID-19 has influenced their preventive behaviors (e.g., social distancing measures, compliance with guidelines, wearing masks, etc.) in

various ways.[66,70,71] More importantly, studies conducted in the context of contact-tracing technologies also suggest that the perceived threat and anxiety of COVID-19 have significantly affected individuals' decisions in adopting the applications.[29,30,32]

Another source of negative emotions is the contact-tracing technology itself, which is used to help contain the spread of COVID-19. Scholars have specifically addressed the potential privacy risks related to health information technology since the 1990s.[50,54,72] The present study was conducted in the context of digital contact tracing, which is an AI technology-based method. Although digital contact tracing has demonstrated effectiveness in augmenting the quality of contact tracing and thus has been supported by many governments and organizations,[7,26] privacy concerns have hindered the global adoption of the technologies (Chan & Saqib, 2021),[9] and many countries are currently working to overcome these barriers.[7] Before the advent of current AI technology, researchers in the 1990s focused on computer anxiety to understand people's uneasy, apprehensive, or fearful feelings caused by privacy concerns about computer use.[73] AI technology not only interprets and learns from external data but also exhibits flexible adaptation abilities.[74]

Therefore, as digital contact tracing suggests, AI technologies have been widely used to replace human beings and their role in making judgments.[46] In today's society, it is possible that AI technology intensifies computer-related anxieties.[75] Recent studies have shown that concerns about AI threats have been rapidly increasing.[76] Types of worries have also diversified and increased, including fear of loss of control of AI, concerns about privacy and surveillance, technological unemployment, fake news, and other ethical concerns. In particular, individuals' privacy concerns regarding the use of AI-based technology, such as COVID-19 contact-tracing technologies, contribute powerfully to their anxiety about AI technology. Recent studies demonstrate that the public has privacy concerns when it comes to using contact-tracing applications.[8–12,31–34]

As discussed in the previous section, it is possible that perceived net equity positively influences individuals' uncertainty reduction regarding the risks and benefits of contact-tracing technologies and their intentions to adopt the technology. However, it is unclear how individuals' anxieties about the COVID-19 pandemic and AI technology affect the associations among perceived net equity, uncertainty reduction, and intentions to adopt contact-tracing applications. However, as many social psychologists have theorized, we can assume that these emotional feelings and processes that are based on individuals' appraisals may guide subsequent cognition (i.e., perceived uncertainty) and decision-making about the adoption of the contact-tracing technologies.[23,63] Emotions often enhance or weaken the strength with which a belief (e.g., net equity) is held.[77] Specifically, anxiety motivates people to carefully consider various alternatives and take actions against a threat even when diverse viewpoints and information may challenge their existing attitudes.[78] Therefore, it is possible that cost–benefit analysis regarding the adoption of contact-tracing technologies and perceived net equity and uncertainty based on a calculus and subsequent decision-making can be affected by individuals' anxiety. However, the question remains as to how such anxiety has an influence on the process of decision-making because the empirical results diverge on this point (Li et al., 2014).[51] In this spirit, we hypothesized the following and asked the subsequent research questions:

H4: AI anxiety will moderate the associations (a) between perceived net equity and perceived level of uncertainty (i.e., uncertainty reduction) and (b) between perceived net equity and intention to adopt a COVID-19 contact-tracing application.

H5: Anxiety of COVID-19 will moderate the associations (a) between perceived net equity and perceived level of uncertainty (i.e., uncertainty reduction) and (b) between perceived net equity and intention to adopt a COVID-19 contact-tracing application.

RQ1: How does the effect of perceived net equity on the perceived level of uncertainty and intention to adopt a contact-tracing technology vary according to the functions of AI anxiety and COVID-19 anxiety?

RQ2: Does the mediating role of the perceived level of uncertainty linking perceived net equity and the intention to adopt a COVID-19 contact-tracing application vary according to the functions of AI anxiety and COVID-19 anxiety?

Methods

Sample and data collection

The data for the present study were collected through a self-administered online survey conducted on July 31 and August 1, 2020. We started this research project as soon as possible, after contact tracing appeared in the media as a potentially effective method that could help contain the spread of the virus. In early 2020, Google and Apple both released new technology to help with coronavirus contact tracing, which appeared in many headlines in the news media prior to our survey. Amazon's Mechanical Turk (MTurk) was employed to recruit adult participants in the United States. Although it does not produce a non-probabilistic sample, an online survey based on crowdsourcing (e.g., MTurk) provides benefits, such as targeting a diverse population of online users.[79] Eligibility was

restricted to US-based individuals who were 18 years or older.

Participants were first asked to read the participation information sheet (PIS) approved by the Institutional Review Board (IRB), which provided brief information about the study, potential risks and benefits of the study, participants' rights, and contact information of the principal investigator. Once they had perused the information sheet, they were requested to express whether or not they consent to participate in the research. Only those who replied affirmatively with "Yes, I wish to participate" were permitted to proceed to the subsequent query in the survey. They then responded to a series of survey items employed to measure the variables of interest. Typically, it took about 15 min to complete the survey, and each respondent was paid 1.8 USD for completing it. To prevent participants from taking the survey more than once, we assigned a qualification type to individuals who had already completed the survey. Of the 432 total participants, 418 individuals who completed the survey in a reasonable amount of time (i.e., longer than one-third of the median duration) with no missing values were included in the dataset.

Our survey sample consisted of 418 valid cases, of which 155 (37.1%) were female and 281 (67.2%) were younger than 40 years of age. A majority ($n = 329$; 78.7%) were white. The sample was overrepresented by males and white individuals. As such, the effects of gender and ethnicity were statistically controlled in our data analyses, as reported in the Results section.

Measures

All the variables were assessed through multiple-item scales adapted from pre-validated measures. A five-point Likert scale was used throughout, except for fear (seven-point scale) (see Appendix A for the items and descriptive statistics for each variable).

Behavioral intentions. Behavioral intentions to adopt digital contact tracing were assessed using a three-item scale ($M = 3.71$, $SD = 1.13$; $\alpha = .91$) adapted from Venkatesh et al.[80] and Angst and Agarwal.'s[81] studies. A sample item includes "I intend to use a COVID-19 contact-tracing application in the near future."

Perceived net equity. Perceived net equity is defined as the degree to which the benefits of a contact-tracing application for COVID-19 prevention are perceived to outweigh potential privacy risks. This was assessed by a five-item scale ($M = 3.70$, $SD = .90$; $\alpha = .89$) adapted from Esmaeilzadeh[54] and Sirdeshmukh et al.'s[82] studies. A sample item includes "The advantages of electronic data sharing for COVID-19 prevention outweigh the potential privacy risks."

Low level of uncertainty. We measured the perceived low level of uncertainty of the benefits and risks of using a contact-tracing application using a five-item scale ($M = 3.83$, $SD = .83$; $\alpha = .84$) adapted from Venkatraman et al.'s study.[83] A sample item includes "I'm certain about the benefit and risk of using a contract tracing application to prevent infectious diseases such as COVID-19." Higher values indicated a "lower" level of uncertainty.

Anxiety toward COVID-19 risks. Anticipated anxiety/fear toward the COVID-19 risks was measured by a six-item scale ($M = 2.96$, $SD = .98$; $\alpha = .91$) adapted from Witte's[84] study. Respondents were asked to think about the possible consequences posed to them by getting infected with COVID-19 and indicate their feelings, such as fright, anxiety, perverseness, and uneasiness, using a seven-point scale, where 1 meant "none of this feeling" and 7 meant "a lot of this feeling."

AI technology anxiety. The extent to which an individual was anxious about AI technology was measured using a four-item scale ($M = 3.47$, $SD = .99$; $\alpha = .86$) adapted from Parasuraman and Igbaria's[73] study. A sample item includes "AI technology is a real threat to privacy."

Data analysis

The statistical analyses were performed using PROCESS mcro.[85] Model 10 was employed to examine the moderated mediation research model (see Figure 1), which contains an independent variable (perceived net equity), a mediator (uncertainty), a dependent variable (behavioral intention), and two moderators (COVID-19 anxiety and AI anxiety). Demographic variables, such as gender, ethnicity, income, and education level, were added as control variables. Indirect effects and their significance were estimated using bias-corrected bootstrap ($n = 5000$ resampling) confidence intervals (CI).

Results

Table 1 presents the results of statistical analyses. H1 and H2 predicted that perceived net equity would be positively associated with low levels of perceived uncertainty regarding a COVID-19 contact-tracing application (H1) and intentions to adopt it (H2). The results showed that perceived net equity had a significant association with uncertainty ($B = .43$, SE = . 17, $p = .014$) and behavioral intention ($B = .98$, SE = . 16, $p < .001$). Hence, H1 and H2 were supported. H3 predicted that low levels of perceived uncertainty are positively associated with intentions to adopt a COVID-19 contact-tracing application, thereby suggesting that a perceived level of uncertainty mediates the associations between perceived net equity and adoption intentions.

Table 1. Predictors of low level of uncertainty and intentions to adopt a contact-tracing application.

	Low Level of Uncertainty					*Intentions to Adopt a Contact-Tracing Application*				
	B	SE	*p*-value	LLCI	ULCI	*B*	SE	*p*-value	LLCI	UICI
Constant	1.60	.71	.026	.196	3.000	−1.24	.65	.058	−2.528	.042
Ethnicity[a]	.05	.04	.215	−.031	.139	−.02	.04	.661	−.095	.060
Gender[b]	−.04	.08	.636	−.184	.113	.04	.07	.575	−.097	.175
Education[c]	.09	.05	.087	−.013	.188	.10*	.05	.031	.010	.194
Income[d]	−.06*	.03	.031	−.106	−.005	−.01	.02	.724	−.054	.038
Perceived net equity	.43*	.17	.014	.090	.775	.98***	.16	.000	.663	1.292
A.I. anxiety	.56***	.14	.000	.284	.830	−.22	.13	.091	.473	.035
COVID-19 anxiety	−.56***	.15	.000	−.847	−.270	.54***	.14	.000	.275	.811
Low Level of Uncertainty	-	-	-	-	-	.25***	.05	.000	.165	.342
Perceived net equity × A.I. anxiety	−.14***	.04	.000	−.208	−.066	.04	.03	.194	−.022	.109
Perceived net equity × COVID-19 anxiety	.17***	.04	.000	.090	.242	−.13***	.04	.001[e]	−.196	−.054

Note. a: White = 0, Ethnic minorities = 1; b: male = 0, female = 1; c: 4 year degree or higher = 0, Some college or 2 year degree or less = 1; and d: 40,000 USD or more = 0, 39,999 USD or less = 1.
e: $p = .0006$. *$p < .05$; **$p < .01$; ***$p < .001$.

The results showed that low levels of uncertainty had a positive association with behavioral intention ($B = .25$, SE = . 05, $p < .001$). Hence, H3 was supported.

H4 predicted that AI anxiety moderates the associations between perceived net equity and perceived level of uncertainty (H4a) and between perceived net equity and intentions to adopt a COVID-19 contact-tracing application (H4b). As Table 1 shows, the interaction effect (perceived net equity*AI anxiety) on uncertainty was significant ($B =$ -.14, SE = .04, $p < .001$). As such, the negative interaction effect suggests that the positive association between perceived net equity and low levels of uncertainty is likely to reduce when AI anxiety is high. However, their interaction effect on behavioral intention was nonsignificant ($B = .04$, SE = . 03, $p = .194$). Therefore, H4a was supported, but H4b was not supported.

H5 predicted that the anxiety of COVID-19 moderates the associations between perceived net equity and perceived level of uncertainty (H5a) and between perceived net equity and intentions to adopt a COVID-19 contact-tracing application (H5b). As Table 1 shows, the interaction effect (perceived net equity * COVID-19 anxiety) on the low level of uncertainty ($B = .17$, SE = . 04, $p < .001$) and behavioral intention ($B = -.13$ SE = . 04, $p < .001$) were significant. The positive interaction effect on the low level of uncertainty suggests that the positive association between perceived net equity and low levels of uncertainty is likely to increase when COVID-19 anxiety is high. The negative interaction effect on behavioral intentions suggests that the association between perceived net equity and intentions to adopt a contact-tracing application is likely to decrease when COVID-19 anxiety is high (see Figure 2-2 and the discussion section for details and further explanations). Therefore, H5a and H5b were supported.

RQ1 asked the following question: How does the effect of perceived net equity on the perceived level of uncertainty and intention to adopt a contact-tracing application vary according to the functions of AI anxiety and COVID-19 anxiety? Table 2 shows conditional effects of perceived net equity on low levels of uncertainty and intentions to adopt a contact-tracing application at values of the moderators. The results showed that two different types of negative emotions have differing implications. Specifically, perceived net equity, when coupled with high anxiety about disease risks (i.e., COVID-19), increases certainty (= low levels of uncertainty) of technology use (Figure 2-1) and behavioral intentions (Figure 2-2) to adopt the technology. In contrast, when coupled with high anxiety about remedies

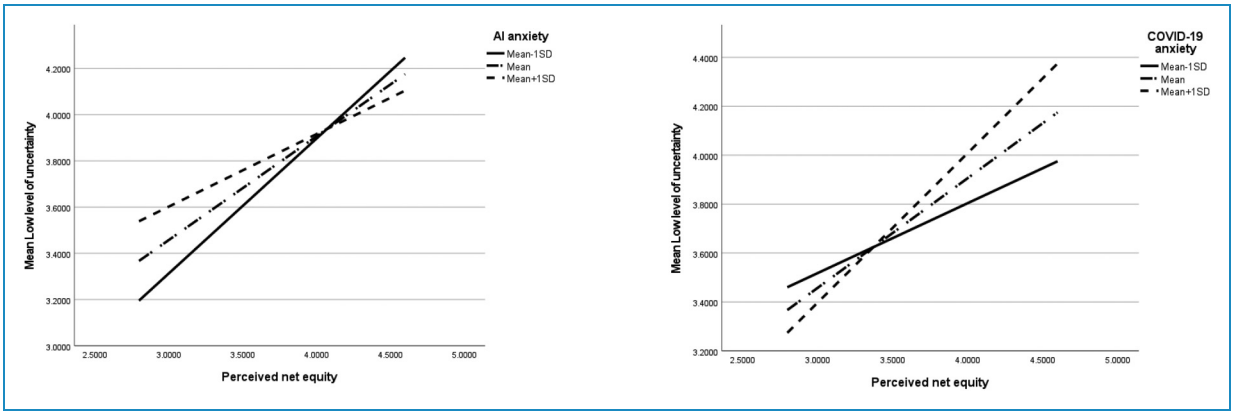

Figure 2-1. Conditional Effects of Perceived Net Equity on Low Level of Uncertainty at Values of the Moderator.

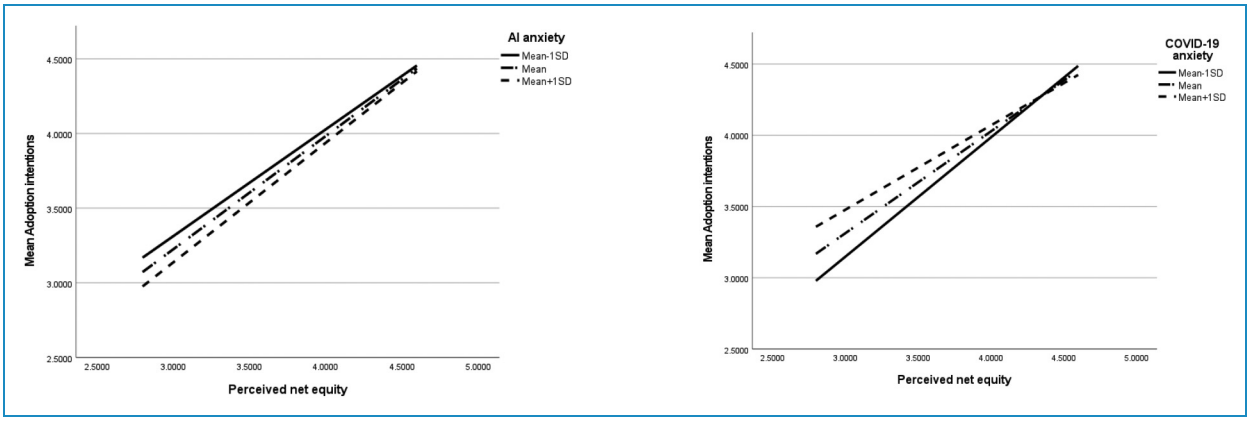

Figure 2-2. Conditional Effects of Perceived Net Equity on Intentions to adopt a Contact-Tracing Application at Values of the Moderator.

(i.e., AI technology anxiety), perceived net equity decreases the certainty of technology use (Figure 2-1).

RQ2 asked the following question: Does the mediating role of the perceived level of uncertainty linking perceived net equity and intention to adopt a COVID-19 contact-tracing application vary according to the functions of AI anxiety and COVID-19 anxiety? Table 2 shows conditional effects of perceived net equity on intentions to adopt a contact-tracing application with values of the moderators. Subsequently, Table 3 shows mediating (indirect) effects of uncertainty across different levels of COVID-19 and AI anxiety, as well as partial moderated mediation effects for each moderator. As Table 3 shows, the mediation effects were significant across the board, but their magnitudes varied significantly. More specifically, perceived net equity led behavioral intentions to adopt a contact-tracing application by lowering uncertainty (or increasing certainty), but the positive mediation effects weakened as anxiety about AI technologies increased. On the contrary, such mediation effects were amplified as anxiety about risks (COVID-19) increased. Indices of partial moderated mediation effects suggest that the mediation effect of uncertainty was moderated significantly by both AI anxiety (index: -.03, C.I.: -.07, .-01) and COVID-19 anxiety (index: .04, C.I.: .01, .08).

In summary, the results generally supported the research model and hypotheses proposed in this study. Specifically, all hypotheses were supported, except for H4b.

Discussion

In this study, we investigated the role of negative affect, perceived net equity, and perceived levels of uncertainty in individuals' adoption of AI-based contact-tracing technology to identify both affect- and cognition-based factors that influence the public's online privacy decision-making during the COVID-19 pandemic. We also explored how the two types of anxiety regarding AI technology and COVID-19 moderate the associations among perceived levels of uncertainty, perceived net equity, and intentions to adopt the technology. The results of this study provide

Table 2. Conditional effects of perceived net equity on low level of uncertainty and intentions to adopt a contact-tracing application at values of the moderators (Figures 2-1 and 2-2).

		Low Level of Uncertainty					*Intentions to Adopt a Contact-Tracing Application*				
A.I. anxiety	COVID-19 anxiety	*b*	*se*	*p*-value	LLCI	ULCI	*b*	*se*	*p*-value	LLCI	ULCI
Low	Low	.42	.07	.000	.292	.550	.84	.06	.000	.714	.961
Low	Medium	.58	.06	.000	.458	.710	.71	.06	.000	.589	.841
Low	High	.75	.08	.000	.585	.909	.59	.08	.000	.430	.754
Medium	Low	.29	.05	.000	.189	.384	.88	.05	.000	.788	.973
Medium	Medium	.45	.05	.000	.351	.547	.76	.05	.000	.660	.856
Medium	High	.61	.07	.000	.467	.756	.63	.07	.000	.492	.777
High	Low	.15	.06	.007	.042	.262	.92	.05	.000	.823	.024
High	Medium	.31	.06	.000	.200	.428	.80	.05	.000	.693	.908
High	High	.48	.08	.000	.318	.635	.68	.08	.000	.527	.828

Table 3. Conditional mediation effects of low level of uncertainty at values of the moderators.

		Perceived Net Equity -> Low Level of Uncertainty -> Intentions to adopt a Contact-Tracing Application			
A.I. anxiety	COVID-19 anxiety	*b*	Boot *se*	Boot LLCI	Boot ULCI
Low	Low	.11*	.04	.049	.192
Low	Medium	.15*	.04	.078	.243
Low	High	.19*	.05	.101	.345
Medium	Low	.08*	.03	.032	.132
Medium	Medium	.11*	.03	.060	.185
Medium	High	.16*	.04	.081	.252
High	Low	.04*	.02	.002	.090
High	Medium	.08*	.03	.036	.143
High	High	.12*	.04	.058	.210

Note. *significant indirect effect.

several important theoretical and practical implications for the current pandemic situation, as well as for future studies regarding the public's adoption of new health technologies, particularly in a context where tradeoffs between privacy risks and public health coexist.

First, the results suggest that a cost–benefit analysis based on a privacy calculus provides a direct way to increase individuals' intentions to adopt the new technology. According to EIM,[53] individuals evaluate the change caused by a new technology based on the difference between the costs and benefits associated with the technology. In this study, perceived net equity, which reflects the evaluation of the difference between costs and benefits, was positively associated with increased intentions to adopt a COVID-19 contact-tracing application. Individuals' increased intentions that were affected by perceived net equity can be considered the result of a cost–benefit analysis comparing privacy risks (e.g., privacy concerns) and individual and social benefits (e.g., reduced danger of the COVID-19 spread) of adopting contact-tracing technologies. This process suggests how individuals use their rational judgments to make privacy-related decisions, which reflects several existing theories. First, the result is consistent with previous literature on privacy decision-making based on the tradition of a cost–benefit analysis and privacy calculus.[16,18,51] Moreover, given that contact-tracing applications

share individuals' private data, such as health information, this result is well aligned with CPM theory,[48,49] which explains individuals' privacy management based on the benefits and privacy risks of disclosure.

Second, the results of this study highlight the mediating role of uncertainty reduction in the association between perceived net equity and intentions to adopt a new contact-tracing application. Specifically, according to the results, perceived net equity based on a cost–benefit analysis provides a direct way to reduce uncertainty,[14] and uncertainty reduction is positively associated with intentions to adopt a COVID-19 contact-tracing application. Given that individuals' decisions about the new contact-tracing application involve privacy risks, the results highlight the important role of perceived uncertainty in the process of privacy-related decision-making. Such decision-making often involves incomplete risk information, ambiguity, and uncertainty.[13] People are intolerant of uncertainty, which may negatively affect their decision-making.[36,37,39] According to Knight's economic model of risk and uncertainty,[35] it is natural that reduced uncertainty influences individuals' decision-making involving privacy risks. Consistent with the existing literature, the results of this study suggest that reduced uncertainty may positively contribute to individuals' decision-making about adopting new contact-tracing technology.

In addition, according to URT,[41] individuals are inherently motivated to reduce uncertainty by gathering information to make better plans and achieve goals.[15] As an explanatory form of knowledge that may reduce uncertainty, perceived net equity is positively associated with low levels of uncertainty regarding the benefits and risks of a COVID-19 contact-tracing application. This suggests that rational judgments based on existing knowledge may affect individuals' perceptions of reduced uncertainty, which can influence people's decision-making. Since people are ambiguity averse,[36,40] they want to reduce uncertainty based on existing perceptions and/or knowledge before making a decision. The mediating effect of reduced uncertainty on the association between perceived net equity and adoption intentions highlights the function of uncertainty at the intermediate stage of a privacy-related decision-making process.

Third, this study makes a further theoretical contribution by investigating the influence of affect-based factors on the process of individuals' rational judgment and privacy decision-making. To explore the effect of an affect-based factor, we focused on individuals' anxieties regarding AI technology (i.e., remedy) and COVID-19 risks (i.e., disease). According to the results of this study, anxieties regarding both AI technology and COVID-19 risks moderate the associations among perceived net equity, perceived levels of uncertainty (i.e., uncertainty reduction), and intentions to adopt the contact-tracing technology. Although AI anxiety failed to moderate the association between perceived net equity and adoption intentions, overall, the results suggest that not only rational judgments but also affective reactions to risks influence individuals' perceptions and privacy-related decision-making regarding a new technology. This result is consistent with previous literature regarding cognitive emotion theories (or appraisal theory [Lazarus et al., 1970; Scherer, 2001]) and several relevant research studies conducted in the context of risk communication[19,20,59,60] in that emotions aroused by cognitive evaluations of risks (i.e., risks of COVID-19 and AI technology-based privacy) affect subsequent cognitive and judgment processes as well as decision-making about the risks. Moreover, these results suggest that affect is a necessary and integral part of the process of privacy-related decision-making, particularly in an uncertain situation like the COVID-19 pandemic.[51] The differences between these two affect-based moderator roles (i.e., COVID-19 anxiety and AI anxiety) in the process of individuals' decision-making are discussed in the following section.

Finally, the results of this study highlight the importance of negative affect and distinguish between the sources of affect in the process of privacy-related decision-making. In this study, we tried to explain how the effect of perceived net equity on perceived uncertainty and intentions to adopt the contact-tracing application varies according to the functions of AI anxiety and COVID-19 anxiety. According to the results of this study, individuals' anxieties regarding AI technology (i.e., remedy) and COVID-19 risks (i.e., disease) had different moderation effects. Specifically, the results suggest that the positive association between perceived net equity and low levels of uncertainty is likely to increase when COVID-19 anxiety is high, whereas the positive association between the two variables is likely to reduce when AI anxiety is high. Moreover, while the positive association between perceived net equity and intentions to adopt a contact-tracing application is likely to decrease when COVID-19 anxiety is high, no moderation effect of AI anxiety on the same association was found. To understand the varied roles of the two types of anxiety, it is necessary to focus on the difference between the two types of risks that construct both anxieties: (1) risks related to COVID-19 and (2) privacy risks related to the adoption of an AI technology-based contact-tracing application. While AI anxiety is an emotional response to potential risks related to the AI technology's invasion of individuals' privacy, anxiety over COVID-19 involves disease-related risks, such as its infection and spread. Each type of risk functions as a trade-off with the other.

Therefore, it makes sense that these two types of anxieties have inverse effects on the association between perceived net equity and perceived uncertainty (Figures 2-1 and 2-2). More specifically, when COVID-19 anxiety is high, perceived net equity might be able to successfully reduce uncertainty regarding the risks and benefits of a contact-tracing application by highlighting its positive

function in containing disease risks. However, when AI anxiety is high, perceived net equity will hardly be able to reduce uncertainty because of the potential technology-related risks (e.g., privacy loss) about which users are anxious. This affective reaction is different from cognitive judgments, such as perceived net equity. Although individuals may rationally calculate potential benefits and risks and cognitively perceive net equity, they may still experience negative emotions caused by perceived threats (i.e., AI technology-based privacy risks). This result is similar to the case of other remedies, such as COVID-19 vaccines. For example, people's fear of adverse effects and ambiguous or uncertain benefits of receiving the vaccination may contribute to COVID-19 vaccine hesitancy.[86]

In terms of the interaction effect on the association between perceived net equity and adoption intentions, we can also contemplate the difference between the two types of risks and anxieties. The findings showed a significant interaction effect of COVID-19 anxiety, although no interaction effect of AI anxiety on this association was found. As Figure 2-2 shows, the negative interaction effect of COVID-19 anxiety on adoption intentions is pronounced among those who had lower levels of perceived net equity. This result suggests that people with low perceived net equity were less likely to adopt a contact-tracing application, but this tendency was reduced when their COVID-19 anxiety was high. Namely, people's anxiety over the disease risks was helpful in increasing the effect of perceived net equity on their adoption intentions when their perceptions of net equity were low.

Overall, consistent with the existing literature, the results of this study suggest that emotions significantly influence people's privacy-related decision-making processes. At the same time, our findings highlight the importance of the sources of negative affect, and how the differing sources of emotion influence the association between rational judgment, perceptions, and decision-making about a new contact-tracing technology. The differing moderation effect of the different types of anxiety suggests that affect can be rational, which makes information meaningful for decision-making.[87]

Implications for policy and practice on privacy decision-making

The results of this study emphasize the necessity of considering both the cognitive and affective aspects of public risk communication, particularly in relation to the adoption of contact-tracing applications. In this study, perceived net equity, which reflects the evaluation of the difference between costs and benefits, significantly increased people's intentions to adopt a COVID-19 contact-tracing application by decreasing their perceptions of uncertainty about the new technology. This suggests that it is important for governments and public practitioners to help the public make rational judgments and decisions by providing unambiguous communication that reduces uncertainty. Moreover, it would be important to clearly communicate the benefits of new contact-tracing technologies so that the public can perceive positive net equity in their adoption decisions. At the same time, governments and public practitioners should provide clear information as to how the collected data may be used and how individuals' privacy can be protected during data use to reduce the public's perceptions of privacy issues.

According to the results of this study, not only rational judgments but also affective reactions to risks influence individuals' perceptions and privacy-related decision-making regarding a new technology. Therefore, affective aspects should be considered in the process of public communication regarding COVID-19 contact-tracing technologies. To ensure the successful adoption of a contact-tracing application by the public, it may be necessary for governments and health practitioners to adequately emphasize negative emotions, such as fear and anxiety. This is because risk-related negative emotions (e.g., COVID-19 anxiety) can reduce uncertainty and increase the positive impact of perceived net equity on adoption intentions. However, it is crucial to exercise caution when communicating about potential technology-related risks (e.g., privacy loss), as the anxiety posed by them may exacerbate the public's perceptions of uncertainty around a new technology, reducing adoption intentions. In addition, policymakers and public practitioners should reduce people's technology-related anxiety by clearly communicating about data use policies and security measures and by fostering their trust in relevant organizations, such as governments and technology companies, as well as the AI technology itself. This will require the implementation of a variety of strategies, such as frequent communication and delivery of personalized messages tailored to individual needs and concerns.[88]

Limitations and future research

Although this study provides several novel findings, it is important to acknowledge its limitations. First, our sample included higher proportions of male and white participants, which suggests some limitations in the generalizability of our results. Moreover, it is necessary to acknowledge that there may be differences between MTurk workers and the general population when using crowdsourcing platforms like Amazon MTurk.[89] This has the potential to affect the variables of interest in the study. However, some scholars argue that MTurk participants are slightly more demographically diverse than standard Internet samples and are reliable as those obtained via traditional methods.[90] The overrepresentation of male and

white participants using the crowdsourcing platforms in this study may suggest that white male individuals will also have a greater interest in contact-tracing technologies compared to females and other minority populations. However, to minimize this potential limitation related to generalizability, we controlled several demographic variables, including gender and ethnicity, in our regression models. Second, since this study is based on cross-sectional data, the possibility of reverse causation can be considered a limitation. Moreover, we could have observed the trends by focusing on multiple landmark events related to COVID-19 and contact-tracing technologies and collecting multiple data around the important events. Future studies in similar contexts should use multiple data points to provide more meaningful findings and general conclusions about trends.

Despite these limitations, this study still provides important contributions to the growing body of research on privacy management and decision-making in the contexts of AI-based health technology and online communication. Specifically, we extended the scope of the privacy-related decision-making process by exploring the effect of both affect- and cognition-based factors on the public's online privacy decision-making and the role of perceived uncertainty in the intermediate stage of the decision-making process during the COVID-19 pandemic. Moreover, our model may be applicable to future studies investigating the process of privacy-related decision-making in various contexts, including contact-tracing technologies, AI-based healthcare, and health information sharing.

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Appendix A Variables, Items, and Descriptive Statistics.

Variables	Items	*M* (*SD*)	α
Behavioral Intention	I would download a COVID-19 contact-tracing app	3.71 (1.13)	.91
	I am willing to recommend that others download a COVID-19 contact-tracing app		
	I intend to use a COVID-19 contact-tracing app in the near future		
Perceived Net Equity	The advantages of electronic data sharing for COVID-19 prevention outweigh the potential privacy risks	3.70 (.90)	.89
	Compared to the possible privacy risks, the use of electronic data sharing for COVID-19 prevention by governments or organizations is beneficial to me		
	Compared to the likely privacy concerns, gains of using electronic data sharing for COVID-19 prevention are greater		
	Compared to the potential privacy risk I need to bear, electronic data sharing for COVID-19 prevention is worthwhile to me		
	Overall, electronic data sharing use for COVID-19 prevention provides me good value		
Low Level of Uncertainty	I'm certain about the benefit and risk of using a contract tracing app to prevent infectious diseases such as COVID-19	3.83 (.83)	.84
	I fully understand the benefit and risk of using a contract tracing app to prevent infectious diseases such as COVID-19		
	I am confident that I know the expected outcomes of using a COVID-19 contract tracing app		
	I have all the relevant information I need to make a decision to adopt a COVID-19 contract tracing app		
	I have sufficient information to make a decision to adopt a COVID-19 contract tracing app		
COVID-19 Anxiety	When you think about the possible consequences posed to you by getting infected with COVID-19: How much fright do you have?	2.96 (.98)	.91
	How much nervousness do you have?		
	How much anxiety do you have?		
	How much uneasiness do you have?		
	How much tension do you have?		
AI Anxiety	AI technology is a real threat to privacy	3.47 (.99)	.86
	I am afraid that AI technology will misuse my data		
	I am anxious and concerned about the pace of automation caused by AI technology		
	I am often frustrated by the increasing effect of AI technology on my personal life and privacy		