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Uncertainty and Privacy Management of the South Korean Public During the COVID-19 Pandemic: Adoption Intentions for AI-Based Digital Contact-Tracing Technology

SOO JUNG HONG♦
HICHANG CHO
National University of Singapore, Singapore

This study explores the factors influencing the intentions of the South Korean public to adopt contact-tracing technologies during the COVID-19 pandemic. Specifically, we combined the privacy calculus model with the impact of perceived uncertainty on adoption intentions and tested it with various contextual and cognitive factors. 444 individuals were surveyed on August 1, 2020, and the data were analyzed with structural equation modeling. Privacy concerns were found to be positively associated with perceived uncertainty and negatively associated with adoption intentions. On the other hand, perceived benefits showed a positive relationship with adoption intentions. Trust in government was negatively associated with perceived uncertainty, and trust in AI technology and perceived stigma had favorable effects on adoption intentions by lowering uncertainty. Finally, perceived uncertainty was negatively associated with the intention to adopt contact-tracing technology. The findings suggest ways to increase intentions to adopt new technologies during pandemics by lowering individual uncertainty associated with digital contact-tracing technologies that involve tradeoffs between the public good and privacy risks.

Keywords: contact-tracing, privacy calculus, risk perception, uncertainty, trust, stigma

As a health technology, AI-based digital contact-tracing can monitor the spread of infectious diseases by determining contact between users and infected people and by discovering new hotspots through fast and precise data collection (Bengio et al., 2020; Kricka et al., 2020). Digital contact-tracing has been endorsed by many governments and organizations (Zhang, Kreps, McMurry, & McCain, 2020), and countries have implemented large-scale technology-based tracking measures to limit the spread of COVID-19 (Georgieva, Beaunoyer, & Guitton, 2021). However, public concerns about privacy intrusions have hindered the wide adoption of contact-tracing technologies in many countries, including Australia, France, Germany, the United States, and the United Kingdom (Chan & Saqib, 2021; Dowthwaite et al., 2022; Hassandoust, Akhlaghpour, & Johnston, 2021; Meier, Meinert, & Krämer, 2023). In particular, the social acceptability of these new technologies was problematic because of public concerns about privacy risks and low levels of trust in AI technologies and tracking in general (Georgieva et al., 2021).

Soo Jung Hong: cnmhsj@nus.edu.sg
Hichang Cho: hichang_cho@nus.edu.sg
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South Korea is one of the few countries that successfully employed contact tracing to limit the spread of COVID-19 in the early stages by using personal data and isolating infected people (Juneau, Briand, Collazzo, Siebert, & Pueyo, 2023; Lewis, 2020). Moreover, South Korea experienced the largest outbreak (to date) of the Middle East Respiratory Syndrome (MERS) outside the Middle East, which allowed authorities to use data from credit cards and mobile phones to trace individuals' movements and identify anyone who might have been exposed to the virus (Lewis, 2020). Therefore, given that many countries struggled with privacy-related challenges and low uptake rates (Lalmuanawma, Hussain, & Chhakchhuak, 2020; Lewis, 2020), we focused on the South Korean context in this study as an example of successful contact-tracing. Further, we examined the underlying mechanism behind the adoption of the new contact-tracing technology by the Korean public.

People usually attempt to reduce uncertainty before making risk-related decisions. According to the uncertainty reduction theory (URT; Berger, 1979), individuals are inherently motivated to reduce uncertainty through communication by gathering information, making better plans, and achieving goals (Berger & Calabrese, 1975). However, individuals dislike making decisions in uncertain situations (Ellsberg, 1961; Fox & Tversky, 1995). Therefore, perceived uncertainty about the risks and benefits of using contact-tracing technologies can be an important factor that affects decision making about their adoption.

Drawing on the privacy calculus model (Laufer & Wolfe, 1977) and URT (Berger, 1979), we explore the effects of perceived privacy risks and benefits of using contact-tracing technologies on perceived uncertainties about the use of contact-tracing technologies and their effect on intentions to adopt the technology. Moreover, drawing on the extended privacy calculus model (Hong & Cho, 2023), we investigate how social and contextual factors (such as public trust and stigma perceptions about COVID-19) affect perceived uncertainty and intentions to adopt the technology.

Theoretically, we aim to develop a theory-driven research model to understand the factors that affect the public's perceptions of uncertainty and intentions to adopt a new technology that involves tradeoffs between privacy risks and health benefits. More specifically, our primary objective is to empirically test and extend the privacy calculus model by integrating it with the impact of perceived uncertainty on individuals' intentions to adopt the new contact-tracing technology. Practically, we discuss potential ways of reducing the South Korean public's uncertainty associated with a digital contact-tracing technology and of increasing their intentions to adopt the new technology.

Literature Review

Uncertainty and Privacy Calculus

Uncertainty arises when individuals lack adequate information to make precise predictions or effectively differentiate between relevant and irrelevant data (Gifford, Bobbitt, & Slocum, 1979). As a result, uncertainty can be described as an individual's subjective perception of his or her inability to accurately predict a particular outcome (Milliken, 1987). Uncertainty may trigger adverse reactions like fear and anxiety (Hartley & Phelps, 2012). Therefore, according to URT, uncertainty reduction is a goal-

driven process that can be applied to various contexts in which the communicating parties can potentially affect their outcomes (Berger, 1979). Although URT was originally developed to explain interpersonal communications in face-to-face contexts, it has been applied to various research areas, such as social media interactions (Antheunis, Valkenburg, & Peter, 2010) and human-computer interactions (Liu, 2021). This study delves into the uncertainties individuals have about digital contract-tracing technologies using the URT. The primary focus is on privacy concerns (i.e., concerns about privacy risks) associated with these technologies.

Petronio's Communication Privacy Management (CPM) theory highlights how privacy risks stem from individuals' choices to disclose private information and others' violations of privacy rules (Petronio, 2002). It has been applied in various contexts, including doctor-patient interactions and family discussions on sensitive topics like genetic test results. These studies indicate that culture, gender, subjective norms, and trust influence individuals' privacy concerns and management (Hong, 2018; Hong, Drake, Goodman, & Kaphingst, 2020; Petronio, 2002). Similarly, in the realm of digital communication, privacy concerns include fears of privacy violations resulting from sharing sensitive information (Wottrich, van Reijmersdal, & Smit, 2019). Recent studies on privacy concerns posed by contact-tracing technologies have examined the impact of trust, age, gender, and previous experiences of privacy invasion on the adoption of the technologies (Hassandoust et al., 2021; Hong & Cho, 2023; Trkman, Popovič, & Trkman, 2023).

About privacy-related decision making, adopting contact-tracing technologies can be understood within complicated contexts where uncertainty and insufficient risk information play a significant role (Acquisti & Grossklags, 2005). According to the economic model of risk and uncertainty (Knight, 1921), individuals' privacy-related decision making is influenced by unknown outcomes (i.e., uncertainty) and unknown probabilities over outcomes (i.e., ambiguity). Intolerance toward uncertainty negatively impacts decision making, as people are averse to making choices in situations with unknown probabilities (Ellsberg, 1961; Fox & Tversky, 1995). This can be especially evident in critical situations like COVID-19, where communicating uncertainty leads to decision-making delays because of people's discomfort with uncertainty. Therefore, it is necessary to contemplate how to reduce uncertainty and increase the intention to adopt new contact-tracing technologies. In this study, we focus on privacy concerns, perceived social and personal benefits, public trust, and perceived stigma toward COVID-19.

Laufer and Wolfe's (1977) model of privacy calculus focuses on an individual's risk-benefit analysis of situational limitations when performing a specific behavior related to privacy. The essential principle of privacy calculus is that individuals attempt to balance the risks and benefits of disclosing or concealing private information to manage that information (Laufer & Wolfe, 1977). This framework has received significant attention from researchers who are attempting to analyze individuals' self-disclosure and expected risks and benefits in the context of online communication (Trepte et al., 2017). Moreover, previous research studies have identified diverse privacy issues related to digital technology and online communication, including e-data collection, data control, unauthorized secondary use, improper access, location tracking, and awareness related to these practices (Eastin et al., 2016).

The use of digital contact-tracing technology to contain the spread of COVID-19 incurred both privacy risks and personal and social benefits. First, contact-tracing can effectively minimize disease spread

and contain an outbreak by mapping out who infected people have been in contact with (Vitak & Zimmer, 2020). Therefore, it can increase a community's sensitivity to and readiness for disease spreading by decreasing errors of detection based on symptoms alone. Importantly, because preventing a disease from spreading quickly can benefit everyone in a community, implementing contact-tracing technology increases everyone's safety within that community (Bengio et al., 2020).

However, despite its effectiveness, there are significant individual and public risks associated with the use of contact-tracing technology, as it relies on the massive collection and sharing of personal information across many organizational boundaries (Redmiles, 2020). Although contract-tracing apps have been developed in at least 46 countries, uptake rates have remained low, and concerns about data privacy and trust deficits have been identified as primary barriers (Lewis, 2020). In many countries, such as Australia, France, Germany, the United States, and the United Kingdom, public apprehensions about privacy infringements have impeded the widespread acceptance of contact-tracing technologies (Chan & Saqib, 2021; Dowthwaite et al., 2022; Hassandoust et al., 2021; Lalmuanawma et al., 2020; Meier et al., 2023). Specifically, limitations remain about control over data, and privacy intrusions, and surveillance; hence, many countries are attempting to overcome these challenges.

The South Korean Context

Compared with other countries, South Korea effectively employed digital surveillance technologies for contact-tracing, using mobile phone location data, security camera footage, and credit card tracking (Juneau et al., 2023). Existing studies highlight that the citizens' tolerance for privacy infringement, combined with the previous MERS experience, contributed to the success (Juneau et al., 2023; Lewis, 2020). The high penetration of smartphones (95%) also aided in the easy adaptability of contact-tracing technologies (Shahroz et al., 2021). However, South Korea has faced criticism for using privacy-infringing digital contact-tracing methods, mainly because of the extensive collection of private data (Ryan, 2020). Despite the proven success of these technologies, gaining full acceptance from citizens remains a distinct challenge, largely because of heightened privacy-related concerns (Park, Choi, & Ko, 2020).

This study was conducted before the widespread adoption of contact-tracing technologies in South Korea. South Korea's digital contact-tracing relied on a mobile application called Korea Internet-Pass (KI-Pass), which should be initially implemented by owners of commercial and noncommercial establishments. KI-Pass initially commenced with 16 model facilities in South Korea in June 2020 and subsequently expanded the number of model facilities in a continuous manner. Citizens were required to authenticate themselves through QR codes using popular daily use apps like Kakao and Naver or their mobile companies' apps. Although existing users are not required to download new apps, they were encouraged to activate a new function within those apps. Consequently, the authentication information of individual citizens is recorded and stored alongside other data, such as mobile phone location and credit card information. As of November 2020, a cumulative total of 260 million authentications had been used across 324,545 facilities in South Korea (Medical World News, 2020). Despite the seamless integration of digital contact-tracing technologies into citizens' daily smartphone usage, there are doubts about their actual willingness to adopt the technology.

Perceived Risk and Benefits, Perceived Uncertainty, and Adoption Intent

The coexistence of risks and benefits can contribute to individuals' perceived uncertainty of using contact-tracing technology. As two features of turbulent environments, risk and uncertainty are often related to decision-making processes (Becker & Knudsen, 2005; Majumdar & Radner, 2008). The relationship between risk and uncertainty is intertwined, as taking action or making decisions that involve risk inherently entails a degree of uncertainty (Pidgeon & Beattie, 1997). Nonetheless, it is important to note that situations based on perceived risk (and benefits) and perceived uncertainty may be distinct from each other (Slovic, Finucane, Peters, & MacGregor, 2002). In the next two paragraphs, we discuss how they are different from each other.

In circumstances characterized by risks, individuals can evaluate the potential risks linked to each alternative before making a decision (Shapira, 1995). Therefore, individuals' decisions to adopt contract-tracing technologies depend on their perceptions of the privacy risks associated with that technology. This process can be understood in conjunction with perceived benefits as well. Specifically, previous literature on affect heuristics suggests an inverse relationship between perceived risks and benefits (Slovic, 2020; Slovic et al., 2002). Moreover, according to recent studies on individuals' intentions to adopt a COVID-19 contact-tracing app and privacy calculus, those more concerned about privacy risk are less likely to adopt and use contact-tracing technology. In contrast, perceived social and personal benefits can positively affect their willingness to adopt the app (Fox, Clohessy, van der Werff, Rosati, & Lynn, 2021; Hong & Cho, 2023). Therefore, individuals' adoption intentions may be negatively linked to their perceived privacy risks, while perceived benefits may positively influence them.

In contrast to risk environments, uncertain situations lead individuals to remain uninformed, lacking the necessary information to make decisions. This renders them unable to assess the probabilities of potential outcomes and the inherent assumed consequences (Tversky & Fox, 2000). In this study, we note that uncertain situations can also be influenced by both perceived risks and benefits. This implies that considering both perceived risks and benefits as key elements in risk-related judgment can assist individuals in assessing potential outcomes, thereby addressing uncertainties associated with the adoption of new technologies. Of course, the decision can be temporary or continuous (Meier et al., 2023), but both perceptions can play a valuable role in alleviating perceived uncertainty surrounding the use of contact-tracing technology by providing essential information. Accordingly, we hypothesize the following:

H1: Perceived privacy concerns (H1-1) and social and personal benefits (H1-2) about the use of COVID-19 contact-tracing technologies are negatively associated with perceived uncertainty about the benefits and risks of using such technologies.

H2-1: Perceived privacy concerns about the use of COVID-19 contact-tracing technologies are negatively associated with the intention to adopt them.

H2-2: Perceived social and personal benefits of using COVID-19 contact-tracing technologies are positively associated with the intention to adopt them.

Public Trust, Stigma, and Uncertainty

Trust is vital to the development and deepening of social relationships, where unspecified favors are exchanged for an indefinite period of time (Blau, 1964). As suggested by the CPM theory (Petronio, 2002), the level of trust individuals have in different public sectors can greatly influence their confidence levels and decision-making processes when it comes to adopting a contact-tracing technology. In the context of this study, trust refers to the confidence that the public places in each sector (e.g., government organizations, tech companies, and new technologies) and their ability to responsibly handle individuals' private data in a manner that prioritizes their best interests and overall well-being (McKnight, Choudhury, & Kacmar, 2002).

Trust includes characteristics such as benevolence (i.e., caring for the well-being of others), integrity (i.e., truthfulness and honesty), and competence (i.e., expertise, professionalism, and competence) (Bhattacherjee, 2002). Therefore, the public's trust is paramount for organizations' risk management processes, particularly when the widespread adoption of contact-tracing technology is required to curb viral transmission effectively (Bengio et al., 2020). Trust also plays a crucial role in computer-mediated communication, as it aids in addressing privacy concerns and facilitates participation in activities that necessitate trust, such as sharing personal information with unfamiliar third parties like private companies or technology developers (McKnight et al., 2002). In addition, public trust in digital technologies has eroded because of indiscriminate data collection by the private sector, chronic privacy breaches, and lax attitudes toward individual privacy (Bengio et al., 2020). In particular, given that digital contact-tracing is an AI technology-based method that relies on tracking systems to determine contact between an infectee and a user (Kricka et al., 2020), individuals' trust in AI technology and data sharing systems would also be paramount. Hence, it is crucial to acknowledge the significance of public trust in government organizations responsible for managing health risks, as well as the technology companies and the digital technology employed in information sharing through contact tracing.

Public trust in both private and public sectors can enhance the perceived individual and social benefits of adopting new technology (Hong & Cho, 2023), reducing uncertainty surrounding reciprocation and cultivating a sense of obligation (Blau, 1964). Therefore, individuals' trust in government, tech companies, and AI technology involving data-sharing systems can reduce uncertainty pertaining to the use of contact-tracing technology while increasing perceived obligations. Similarly, several scholars have conceptualized trust as a means of reducing complexity, highlighting that it can mitigate the heightened complexity individuals encounter in low-trust relationships and emphasize potential avenues for necessary actions (Colquitt, LePine, Piccolo, Zapata, & Rich, 2012; Luhmann, 1979). Therefore, trust can reduce people's perceived uncertainty of using new contact-tracing technology in situations where risks and benefits are complicatedly entangled with each other.

Moreover, the fairness heuristic theory suggests that trust guides decisions about whether to cooperate with other social entities (or authorities) when there is uncertainty about potential exploitation or misuse (Lind, 2001). In the context of COVID-19 contact-tracing technologies, it is important for individuals to trust that public and private sector organizations will not misuse their private data, allowing them to reduce uncertainty levels and make judgments about the new technology. Recent studies have suggested

that trust in the government, private distributors, and AI technology involving data-sharing systems can positively influence people's willingness to adopt a COVID-19 contact-tracing app (Hong & Cho, 2023; Kaptchuk et al., 2020). Accordingly, we propose the following hypotheses:

H3: Perceived trust in the government (H3-1), private companies (H3-2), and AI technology (H3-3) are negatively associated with perceived uncertainty about the benefits and risks of the COVID-19 contact-tracing technologies.

H4: Perceived trust in the government (H4-1), private companies (H4-2), and AI technology (H4-3) are positively associated with intentions to adopt the COVID-19 contact-tracing technologies.

Privacy concerns related to the misuse of COVID-19 data and its associated problems encompass various issues, such as the stigmatization of individuals based on their disease status and contact with infected individuals (Bhanot, Singh, Verma, & Sharad, 2021; Logie & Turan, 2020). The term *stigma* was first introduced by Goffman (1990) in reference to the visible characteristics of individuals that society devalues and considers unfit for inclusion in mainstream society (Bhanot et al., 2021). Health-related stigma refers to negative associations between a specific disease and a person or group of people who share certain characteristics related to the disease (Perry & Donini-Lenhoff, 2010).

The stigma of COVID-19 can be regarded as a social process that excludes anyone perceived as a potential source of COVID-19, constituting a potential threat to society (Bhanot et al., 2021). Therefore, stigmatization can increase the suffering of people infected with COVID-19. Because South Korea is a high-context society that shares extensive information and emphasizes social relationships, COVID-19 may involve significant psychological and social meanings in society (Son, Choi, Hwang, & Yang, 2021; Thomas, 1998). Additionally, there have been confirmed COVID-19 cases in South Korea where people have experienced social stigma, feelings of guilt, and negative attitudes from others and society (Son et al., 2021).

A recent study conducted in the United States indicates that individuals who perceive COVID-19 infection as stigmatic tend to have positive views about the importance of contact tracing for prevention (Hong & Cho, 2023). This implies that the risks associated with stigmatization may parallel those inherent in disease infections, thereby strengthening individuals' intentions to embrace technological solutions for disease prevention. Although there is potential for individuals to perceive stigma as a risk factor like privacy concerns in the adoption of new contact-tracing technologies, the results of the U.S. study suggest that individuals with stigma perceptions might be more inclined to perceive less uncertainty about the new technology and more likely to adopt contact-tracing apps (Hong & Cho, 2023). This may be because adopting new technologies for preventing disease is effective in decreasing the risk associated with stigmatization as well. Therefore, in line with the previous study conducted in the United States, we present the following hypotheses:

H5: Perceived COVID-19 stigma is negatively associated with perceived uncertainty about the benefits and risks of the COVID-19 contact-tracing technologies (H5-1) and positively associated with the intention to adopt the COVID-19 contact-tracing technologies (H5-2).

Adoption Intentions and Mediation Effects of Perceived Uncertainty

Contact-tracing technologies enable individuals' private information to be exchanged across organizational boundaries and extend to governments, businesses, and individual users (Kaptchuk et al., 2020; Redmiles, 2020). As discussed previously, individuals' risk-benefit analysis of using contact-tracing technologies and relevant contextual factors (i.e., trust in government, tech companies, and AI technology, and stigma perceptions toward COVID-19) may affect individuals' perceived uncertainty of using a contact-tracing technology and adoption intentions. Previous literature has suggested that people dislike making decisions when in uncertain situations and try to reduce uncertainty before making a risk-related decision (Berger, 1979; Ellsberg, 1961; Fox & Tversky, 1995). Therefore, we hypothesize that perceived uncertainty about the benefits and risks of the COVID-19 contact-tracing technologies decreases individuals' intentions to adopt them. Moreover, in the process of exploring several factors that affect individuals' perceptions of uncertainty and adoption intentions, we further develop and extend the existing privacy calculus model based on the mediating role of perceived uncertainty.

H6: Perceived uncertainty is negatively associated with the intention to adopt COVID-19 contact-tracing technologies.

Methods

Sample and Data Collection

The data for the present study were collected through a self-administered online survey conducted in South Korea on August 1, 2020. A professional research company based in South Korea recruited participants using their research panel, which contains over 7 million global research panelists. Participants read an IRB-approved participant information sheet informing them that the survey was about privacy concerns about contact-tracing technologies for COVID-19 prevention and control. After each person agreed to participate, he or she was provided with information explaining that digital contact tracing is an AI technology-based method of contact tracing. This information covered what COVID-19 contact-tracing apps are and how these apps function to contain the disease.

Our sample size was justified using G*Power 3.1 (Lakens, 2022). To detect a medium effect size (f^2 = 0.15) in a path (regression) model with 7 predictors, a minimum of 153 participants is required to achieve a power of .95. The sample for this study consisted of 444 valid cases, of which 183 (41.2%) were female. The average age of the respondents was 37.53, and most (n = 292, 65.8%) were aged less than 40 years. With regard to education and income levels, most (n = 272; 61.3%) had a college degree (or above) and earned an annual income higher than 40 million Korean Won (n = 262; 59%). The sample was slightly overrepresented by males, the younger generation, and those with higher education and income levels. Accordingly, the effect of these demographic variables was statistically controlled for in our subsequent data analyses, as reported in the results section.

Measures

All the variables were assessed through multiple-item scales adapted from prevalidated measures, and a five-point Likert scale was used throughout. *Intentions* to adopt the contact-tracing technologies were assessed using a three-item scale adapted from Venkatesh, Thong, and Xu (2012; α = 0.92; M = 3.35, SD = 0.89). *Perceived uncertainty* of the benefits and risks of using contact-tracing technologies was assessed using a five-item scale (α = 0.89; M = 2.65, SD = 0.68) adapted from Venkatraman, Aloysius, and Davis (2006). The survey items were reverse coded to ensure that higher values indicate a "higher" level of uncertainty. *Perceived privacy concerns* associated with contact-tracing technologies were assessed using six items (α = 0.92; M = 3.60, SD = 0.84). These were also used by Esmaeilzadeh (2019), who adapted them from research conducted by Whiddett, Hunter, Engelbrecht, and Handy (2006). We assessed the *perceived social and personal benefits* of using contact-tracing technologies by the six-item (α = 0.91; M = 3.80, SD = 0.61) scale used by Esmaeilzadeh (2019), who adapted them from Kim, Joseph, and Ohno-Machado (2015). *Trust in the government, private companies, and technology* were measured using a nine-item scale (three items for each dimension) adapted from McKnight et al. (2002): Trust in the government (α = 0.89; M = 3.01, SD = 0.93), trust in private companies (α = 0.88; M = 2.77, SD = 0.89), and trust in technology (α = 0.91; M = 3.01, SD = 0.81). *Perceived stigma* was measured by four items adapted from Waller, Marlow, and Wardle (2007; α = 0.88; M = 3.17, SD = 0.93).

Results

We tested the research model and hypotheses using a structural equation modeling (SEM) approach. AMOS version 27 was used, employing maximum likelihood (ML) for estimation and testing. A composite scale approach was implemented, constructing variables of interest based on mean scores. To control for the effects of age, gender, education, and income, these variables were added to the research model as control factors and were used to predict each variable in the research model (Richiardi, Pizzi, & Pearce, 2013). All independent variables were allowed to covary. The research model is a fully saturated model, where all observed variables in our research model were predicted to have a relationship with each other. Therefore, conventional model fit indices such as chi-square, comparative fit index (CFI), Tucker-Lewis index (TLI), and normed fit index (NFI) do not provide meaningful evaluations because the saturated model itself lacks the need for assessment (e.g., $\chi 2 = 0$; CFI, TLI, NFI = 1.000). When estimating the indirect effects implied in our research model, we employed the bootstrapping approach using bias-corrected bootstrap (n = 1,000 resampling) and 95% confidence intervals (C.I.).

Figure 1 summarizes the SEM results. In H1, a negative association between privacy concerns and perceived uncertainty about contact-tracing technologies (H1-1) was predicted, in addition to one between perceived benefits and perceived uncertainty (H1-2). The results demonstrated that privacy concerns had a nonsignificant relationship with perceived uncertainty ($\beta = -0.045$, $p = .261$). In contrast, perceived benefits had a negative, significant association with perceived uncertainty ($\beta = -0.222$, $p < .001$). Hence, H1-1 was not supported, and H1-2 was supported.

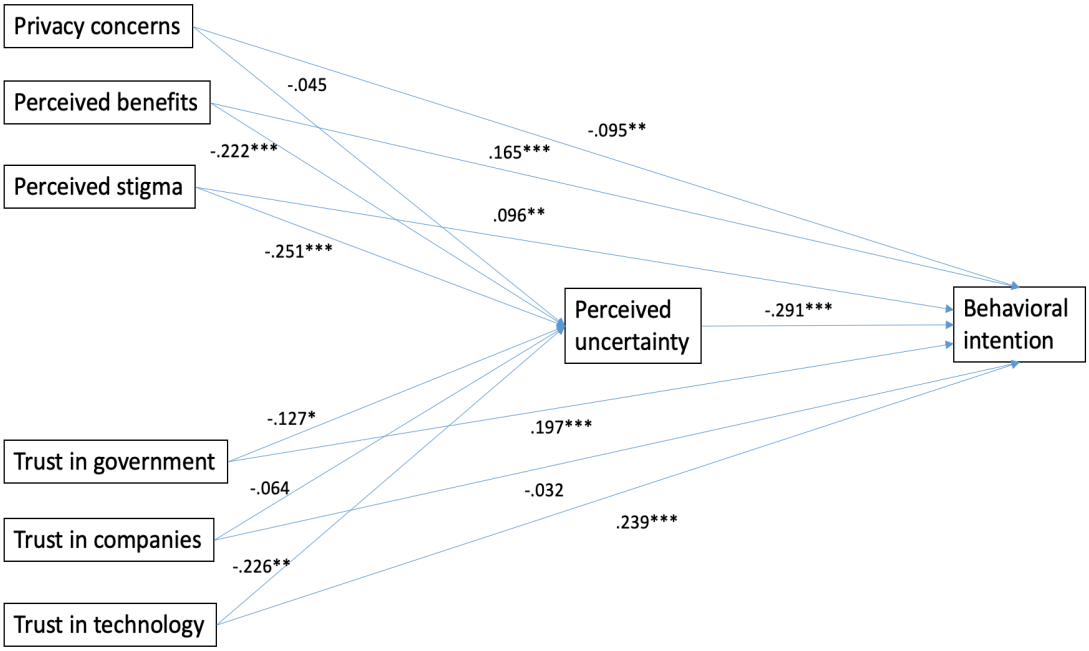

Figure 1. Results of SEM analysis.

Note. * $p < .05$, ** $p < .01$, *** $p < .001$.

In H2, it was predicted that privacy concerns would be negatively associated with intentions to adopt contact-tracing technologies (H2-1), whereas perceived benefits would be positively associated with intention (H2-2). As predicted, privacy concerns had a negative association with behavioral intentions ($\beta = -0.095$, $p = .005$) and perceived benefits had a positive relationship with intentions ($\beta = 0.165$, $p < .001$). These results supported H2-1 and H2-2, suggesting that perceived benefits have a positive direct effect on intentions (or an indirect effect) by reducing uncertainty about the technology (B indirect = 0.094, bias-corrected bootstrap 95% C.I.: 0.052, 0.149). In comparison, privacy concerns appeared to have a negative direct effect on intentions, although their indirect effect via uncertainty was not significant (B indirect = 0.000, bias-corrected bootstrap 95% C.I.: −0.012, 0.000).

In H3, it was predicted that perceived trust in the government (H3-1), private companies (H3-2), and AI technology (H3-3) would be negatively associated with perceived uncertainty. The results indicated trust in the government ($\beta = -0.127$, $p = 0.034$) and trust in AI technology ($\beta = -0.226$, $p = 0.002$) had negative associations with perceived uncertainty. However, trust in private companies had a nonsignificant association with perceived uncertainty ($\beta = -0.064$, $p = 0.378$). Hence, H3-1 and H3-3 were supported, while H3-2 was not supported.

In H4, it was predicted that trust in the government (H4-1), private companies (H4-2), and AI technology (H4-3) would be positively associated with the intention to adopt COVID-19 contact-tracing

technologies. The results indicated that trust in the government (β = 0.197, $p < .001$) and trust in AI technology (β = 0.239, $p < .001$) had a positive association with intentions. However, trust in private companies (β = −0.032, $p = 0.606$) had a nonsignificant association with intention. Hence, H4-1 and H4-3 were supported, and H4-2 was not supported. Taken together, the results indicate that among the three types of trust, trust in AI technology appeared to be the most influential predictor, as it had a favorable direct effect and an indirect effect by decreasing perceived uncertainty about the technology (B indirect = 0.073, bias-corrected bootstrap 95% C.I.: 0.021, 0.140). In comparison, trust in the government had only a direct effect, and its indirect effect via uncertainty was not significant (B indirect = 0.035, bias-corrected bootstrap 95% C.I.: −0.003, 0.081). Trust in private companies appeared to have a minimal role in the context of the present study, as it had nonsignificant effects on intentions either directly or indirectly (B indirect = 0.019, bias-corrected bootstrap 95% C.I.: −0.026, 0.063).

In H5, it was predicted that perceived stigma would be negatively associated with perceived uncertainty (H5-1) and positively with intentions to adopt COVID-19 contact-tracing technologies (H5-2). The results indicated that perceived stigma had a significant, negative association with perceived uncertainty (β = −0.251, $p < .001$) and a positive association with behavioral intentions (β = 0.096, $p = 0.008$). Moreover, its indirect effect on intentions via uncertainty was also significant (B indirect = 0.070, bias-corrected bootstrap 95% C.I.: 0.034, 0.116). Consequently, it appears that the perceived stigma of COVID-19 promotes intentions to adopt contract-tracing technologies, supporting H5-1 and H5-2.

Finally, the results indicated that perceived uncertainty was negatively associated with intentions to adopt COVID-19 contact-tracing technologies (β = −0.291, $p < .001$), lending support for H6. In summation, the results supported most of the hypotheses in our research model. Specifically, 10 hypotheses were supported (H1-2, H2-1, H2-2, H3-1, H3-3, H4-1, H4-3, H5-1, H5-2, and H6), while three were not (H1-1, H3-2, H4-2).

About the control variables, none had a significant association with perceived uncertainty. However, gender (β = 0.068, $p = 0.042$; base group = male), age (β = 0.080, $p = 0.017$), and income (β = −0.073, $p = 0.031$; base group = annual income above 40 million Korean Won) had a significant association with behavioral intentions. The results also suggest that female, older, and high-income individuals are more likely to adopt contact-tracing technologies.

Discussion

In this study, we investigated the South Korean public's perceived uncertainty and adoption intentions about contact-tracing technologies that involve tradeoffs between privacy risks and health benefits. Specifically, we empirically tested and extended the model of privacy calculus by combining the impact of perceived uncertainty on individuals' adoption intentions with respect to the contact-tracing technology. The results of this study suggest potential ways of reducing uncertainty associated with digital contact-tracing technology and increasing intentions to adopt the new technology in a pandemic situation.

First, the results of this study suggest the need to consider the relationship between uncertainty and privacy calculus when investigating individuals' privacy-related decision making. The results

revealed that privacy concerns exhibited a nonsignificant relationship with perceived uncertainty, whereas perceived benefits displayed a significant negative association with it. Importantly, the latter factor influenced adoption intentions indirectly by reducing perceived uncertainty. Adopting contact-tracing technologies can be regarded as a privacy-related decision within complicated contexts where uncertainty and insufficient risk information play significant roles (Acquisti & Grossklags, 2005). Although individuals try to balance the risks and benefits of sharing private information with others (Laufer & Wolfe, 1977), the simultaneous coexistence of risks and benefits can contribute to individuals' perceived uncertainty. Similarly, the results highlight the importance of individuals' perceived uncertainty (derived from privacy calculus) in privacy-related decision making.

Nevertheless, the results also propose that the dynamics of negative and positive evaluations may diverge. We operated under the assumption that both risk and benefit judgments might serve to mitigate uncertainty. As predicted, perceived benefits showcased a positive direct effect and an indirect influence on adoption intentions by diminishing uncertainty about the technology. Conversely, privacy concerns exerted a direct negative impact on adoption intentions. In situations characterized by risk, individuals are better equipped to assess the probability of each alternative before finalizing a decision (Shapira, 1995). In keeping with this pattern in the findings, it can be argued that risk judgments prove beneficial for individuals in deciding upon new technology. Nevertheless, in contrast to perceived benefits, perceived privacy concerns, viewed through the lens of a risk judgment, failed to abate uncertainty.

This outcome can be further discussed through the lens of the economic model of risk and uncertainty (Knight, 1921). The model posits that individuals' decision-making concerning privacy is influenced by both unknown outcomes (uncertainty) and unknown probabilities associated with those outcomes (ambiguity). Although the clear benefits of adopting new technology can reduce uncertainty, privacy concerns reflect the complicated context of the pandemic situation, being more closely related to ambiguity.

In the same vein, Babrow's problematic integration theory (1992) may provide a potential explanation for the nonsignificant result, as it focuses on how individuals evaluate and integrate conflicting information and experiences. In a pandemic situation, the social and personal benefits of adopting new contact-tracing technologies are paramount to containing an infectious disease. According to problematic integration theory (Babrow, 1992), it seems evident that the divergent nature of high privacy-risk perceptions and subsequent privacy concerns associated with contact-tracing technologies pose a considerable obstacle in harmonizing these apprehensions with the anticipated positive outcomes of adopting such technological solutions. The inherent challenge lies in individuals' difficulty when attempting to integrate conflicting information surrounding the perceived risks of using contact-tracing technologies and the potential benefits of their adoption. The presence of this discrepancy highlights the intricate cognitive processes based on unknown possibilities involved in evaluating and reconciling these contrasting factors. Hence, it is plausible that the complex circumstances and possibilities influenced the absence of a significant relationship between individuals' privacy concerns and perceived uncertainty about contact-tracing technology. Therefore, as explained above, future studies can focus on both perceived ambiguity and perceived uncertainty to elucidate this nonsignificant result.

Second, the results suggest that different types of public trust have varying effects on both perceived uncertainty and adoption intentions concerning contact-tracing technologies. In this study, we tested the effect of three types of trust on uncertainty reduction and adoption intentions: Trust in governments, tech companies, and AI technology. As suggested by previous literature, the results indicated that trust can potentially decrease individuals' perceptions of uncertainty when risks and benefits are intricately intertwined (Colquitt et al., 2012; Luhmann, 1979) and assist individuals in making decisions about cooperation with social entities or authorities in situations that are risky and/or uncertain (Lind, 2001). These findings also contribute to the theoretical extension of privacy calculus (Laufer & Wolfe, 1977) by integrating the notion of trust in shaping individuals' privacy management (Petronio, 2002), as well as the influence of perceived uncertainty on decision making about risks (Berger, 1979; Ellsberg, 1961; Fox & Tversky, 1995).

The results indicate that public trust in AI technology had the greatest influence on perceived uncertainty among the three types of trust. Furthermore, trust in the government exhibited both direct and indirect effects on adoption intentions through perceived uncertainty. In contrast, the direct and indirect effects of trust in tech companies were found to be insignificant. This outcome may be because of the likelihood that individuals are not fully aware that private companies also gain advantages from their data. However, trust in AI technology demonstrated an indirect effect through perceived uncertainty and a positive direct effect on adoption intentions. These results indicate that trust in AI technology that involves data-sharing systems is paramount in reducing people's uncertainty about the new technology, which also contributed to the most significant effect of trust in AI technology on adoption intentions via both direct and indirect effects.

Given that contact-tracing technologies are based on AI-based tracking systems that determine contact between an infectee and a user (Kricka et al., 2020), the whole process of information sharing depends on the technology itself. According to the CPM theory (Petronio, 2002), individuals share private information only with trusted others who are expected to protect their privacy. However, the results of this study suggest that in the presence of advanced technology and the changing media environment, technology itself can be more important than human beings or social entities when making privacy-related decisions.

Third, the results of this study suggest that stigma perceptions can help individuals adopt new contact-tracing technologies. According to previous literature, stigma refers to negative associations between a specific disease and a person or group of people (Perry & Donini-Lenhoff, 2010). Furthermore, stigma perceptions negatively influence these individuals' health and well-being (Matsumoto, Santelices, & Lincoln, 2021). Under the COVID-19 pandemic situation, stigmatization also increased the suffering of people infected with the COVID-19 virus (Logie & Turan, 2020; Son et al., 2021). However, according to the results of this study, it would appear that the perceived stigma of COVID-19 can promote an individual's intentions to adopt contact-tracing technologies. More specifically, the results revealed a significant positive association between perceived stigma and adoption intentions, while demonstrating a negative association between perceived stigma and perceived uncertainty about the new technology.

The potential risks of stigmatization are tied to the sensitivity of private information (Petronio, 2002). Nevertheless, the sensitivity of stigma-related information, such as infection or contact with infected individuals, can enhance the mutual advantages of using contact-tracing technologies among users who have established trust. According to a recent study conducted in the United States context, individuals

perceiving high COVID-19-related stigma had high perceptions of reciprocal benefits from adopting contact-tracing technology (Hong & Cho, 2023). Simultaneously, since stigma cannot be detached from the disease infection itself, adopting contact-tracing technologies can help mitigate the potential risks of stigmatization for uninfected individuals by reducing the overall risk of disease. As shown in previous literature as well as in our study results, it appears that both the risks and benefits of using contact-tracing technologies are embedded in an individual's perceptions of stigma. This suggests that perceived stigma, as a potential risk factor, increases individual and reciprocal benefits and promotes adoption intentions by reducing uncertainty about the technology.

Fourth, in this study, we extended the privacy calculus model (Laufer & Wolfe, 1977) by incorporating uncertainty as a mediator. The findings emphasize the importance of reducing uncertainty, which serves as a crucial link between analytic and contextual variables in privacy-related decision making within the expanded model. More specifically, the results of our extended privacy calculus model underscore the important roles of uncertainty-reducing factors discussed above (i.e., perceived benefits, perceived stigma, and trust in government and AI technology) in the complex context of privacy decision making, where conflicting and insufficient risk information is prevalent.

Uncertainty reduction can be understood as a goal-driven process that helps individuals achieve their goals via communicating with other parties, and risk-related decision making is one of the communication contexts in which people try to reduce uncertainty (Berger, 1979; Ellsberg, 1961; Fox & Tversky, 1995). According to the results of this study, perceived uncertainty was negatively associated with intentions to adopt COVID-19 contact-tracing technologies, which immediately reveals the importance of uncertainty reduction to increase intentions to adopt the technology. Although Laufer and Wolfe's (1977) original model of privacy calculus solely concentrated on an individual's evaluation of potential risks and benefits in privacy-related decision making, the outcomes derived from our extended model indicate that the effect of risk-benefit analysis on uncertainty reduction may occur before it influences decision making. Consequently, this finding expands the theoretical implications of the privacy calculus model.

Moreover, this result based on the extended model demonstrates individuals' goal-driven process to reduce uncertainty via analytic effort (such as evaluating the benefits of adopting contact-tracing technologies), which finally influences their decision making. Although privacy concerns did not show any significant effect on perceived uncertainty, as mentioned earlier, this result is also meaningful in that it can be interpreted in light of problematic integration and uncertainty reduction. Similarly, contextual factors (such as trust in government and technology and the perceived stigma of COVID-19) can also be understood as the standard for reducing uncertainty about the technology and adopting contact-tracing technologies. In conclusion, the results of our extended model carry significant theoretical implications by highlighting the need to consider uncertainty reduction as a goal-driven process within models of privacy-related decision making, such as privacy calculus.

Finally, the outcomes of this study carry significant practical implications for policymakers and public practitioners striving to increase the public's adoption of new health technologies, such as digital contact-tracing apps. The findings underscore the necessity of adopting a comprehensive approach to reducing uncertainty in public risk communication, particularly when implementing new health technologies.

To effectively tackle this challenge, governments and public practitioners must take proactive measures to assist the public in mitigating uncertainty. This involves first highlighting the advantages of these technologies and fostering trust in government and data-management systems. Additionally, focused efforts should be directed toward communicating potential privacy risks as well as alleviating subsequent privacy concerns. This encompasses delivering clear and comprehensive communication about the risks and benefits of new technologies, ensuring public understanding of the data-management processes employed by the government and technological systems.

A crucial aspect of this strategy may involve targeted campaigns and initiatives to increase public awareness about the benefits and risks of digital contact-tracing apps and how collected data will be used, as well as how individuals' privacy will be safeguarded. Achieving transparency can be facilitated through these campaigns and relevant informational materials that demystify the data-management processes as well as the risks and benefits associated with the new technology, ultimately increasing public trust and alleviating public concerns surrounding privacy issues. This process will be the first step to increase the public's intentions to adopt the new technology.

Limitations and Future Directions

Although this study provides several important findings, it is necessary to acknowledge its limitations. First, our data were collected in South Korea, and our sample was overrepresented by males, the younger generation, and those with higher education and income levels. This suggests some limitations in the generalizability of our results. To minimize these limitations, we controlled for several demographic variables in our models, including gender, age, education, and income. In addition, although our study was conducted in the South Korean context, we believe that our findings can be helpful to many other countries that are struggling with limitations and concerns about data privacy issues and trust deficits. Second, we measured uncertainty about the risks and benefits of adopting contact-tracing apps as one variable. Future studies should measure uncertainty about risks and benefits separately, consistent with general measures of perceived risks and benefits. Last, since this study was based on cross-sectional data, the possibility of reverse causation could be considered a limitation. Further investigations using longitudinal panel data are required to establish the causal sequence.

Despite these limitations, our findings provide important practical and theoretical contributions to the growing body of research on privacy management and decision making in the context of digital contact-tracing, which can help the public adopt a new health technology in a pandemic situation. Moreover, we extended the scope of the privacy-related decision-making model by exploring the role of uncertainty reduction. More specifically, we combined the privacy calculus framework with the impact of uncertainty to reveal the underlying mechanism of adopting privacy-related technology and the broader effects of analytical and contextual factors related to digital contact tracing. Our theoretical model may apply to future research exploring individuals' intentions to adopt new health technology and share private information for the public good. Future studies can also extend our model based on diverse theoretical frameworks central to the public's adoption intentions about a new technology that involves tradeoffs between the public good and privacy risks.

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