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Research article

Factors driving the acceptance of COVID-19 pandemic mobile contact tracing apps: The influence of security and privacy concerns

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ABSTRACT

The acceptance of COVID-19 mobile contact tracing apps (MCTA) is crucial to curb the spread of the virus and decrease the number of infections. However, the security and privacy concerns (SPC) of COVID-19 MCTA have been called into question. Thus this paper examines the drivers of the acceptance of the COVID-19 pandemic MCTA under the auspices of the influence of SPC from the Chinese perspective based on the modified Unified Theory of Acceptance and Usage of Technology (UTAUT) model. The data generated through a questionnaire based on the convenient sampling technique was analyzed with SPSS by performing hierarchical regression analysis. The results show that the core constructs of UTAUT such as performance expectancy (PE), facilitating conditions (FC), effort expectancy (EE), and social influence (SI) along with mobile self-efficacy (MSE) were significant predictors of individual user acceptance of COVID-19 MCTA. Additionally, the study confirmed that security and privacy concerns were significant in moderating the impact of PE, FC, EE, SI, and MSE on the acceptance of COVID-19 MCTA. The managerial and theoretical implications of these findings for policy-makers, governments, mobile app developers, and researchers are interrogated.

1. Introduction

The emergence of the deadly COVID-19 pandemic has caused many social and economic disruptions around the world since it was declared by the World Health Organization (WHO) as a pandemic with global emergency and concern [1,2]. Digital technology adoption tripled faster as a result of the strategic reaction to the COVID-19 pandemic disruptions and its transformative changes will be felt both at the individual and organizational levels for a long time. Health facilities had to swiftly adapt to technologies to encourage e-health administration systems for health provision during the pandemic [3]. Leadership across the world had to make strategic hard calls concerning the acceptance of technology, emphasizing the prominence of technological progress during the pandemic and the chance to design systems to improve productivity [4]. A great deal of technological and organizational barriers that otherwise could serve as hindrances to technology acceptance [4] had to be overcome to encourage the acceptance of technologies in the pandemic era.

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Technology-driven barriers to technology adoption during the period of COVID-19 include security and privacy concerns, cost savings, technology compatibility, technology infrastructure, technology competence, etc. [5,6]. Top management support, staff support, institutional constraints, and organizational support are some of the organizational-related barriers to technology acceptance in the era of pandemic disruptions [5,6].

The severity of the pandemic led to the imposition of stringent social distancing and lockdown strategies as preventive and control processes to stop the spread of the pandemic among the larger population [7,8]. To reduce the higher levels of COVID-19 mortality and infections, governments and health authorities had to leverage the power of mobile technology to contain the pandemic. Mobile app solutions came in handy to reduce the consequence of the virus on the populace and importantly slow down the risk of cross-contagion instigated by proximity or contact with persons infected [9,10]. Mobile applications (apps) are deemed to be highly accessible, acceptable, and easily utilized and thus were instrumental in supporting social distancing and control measures, especially in terms of providing valuable information about the virus to people [9,11].

Within the Chinese environment, the COVID-19 pandemic mobile contact tracing technology is being utilized by the government and its agencies to screen and control the spread of COVID-19 via systems such as cellphone locality data, history of credit card usage, etc. During the advent of the pandemic, the Chinese authorities instituted a national telecom data analysis system under the control of the Ministry of Information Industry Technology which empowered the telecom companies to provide tracking data/records of individual mobile phone users' locations in the past 30 days at most [12]. The COVID-19 tracing apps were further integrated with other apps (WeChat and AliPay social media apps) with analogous roles in various parts of China to determine the official verification and certification of the health status of people and, depending on the health code status (red, yellow, or green), some forms of restrictions or regulations may apply [12,13]. A green health code is mandatory for individuals to get access to public amenities such as malls, schools, public transportation, restaurants, airports, cinemas hospitals, etc. [14,15]. The utilization of COVID-19 MCTA in China to track and determine the health status of citizens and the general public may have security and privacy concerns/implications for users since the data are gathered and used for public security reasons without appropriate accord and approval from individual users [12,16]. This is even more troublesome when the authorities in charge of the Cyber-security Administration of China mandated the National Health Committees to gather users' records without approval [12]. It has been emphasized that the nature and mechanism of handling, use, and storing of individual information/data by the government and other authorized private-sector agencies are not transparent enough and this may lead to the possibility of abusing users' data/information [12].

Furthermore, amidst the security and privacy concerns (SPC) of COVID-19 MCTA utilization in China [17,18], the ethical and legal environment for the execution of COVID-19 MCTA for infection observation and management purposes are said to be indistinct raising further concerns about its potential risks [19]. Digesting the legal challenges via the examination of the Personal Information Protection Law (PIPL) (*the fundamental law for the protection of personal information in China*), Zhang [19], highlights the need for the government to balance the demand for safeguarding individual rights to the security and privacy of their data and public access to such information to curb the spread of the virus. Moreover, personal security information challenges such as individual user consent, transparency, storage periods, security, and privacy protections have been identified in the usage of COVID-19 MCTA in China [19].

The objective of this paper is to examine the drivers of the individual user acceptance of COVID-19 MCTA under the influence of security and privacy concerns centered on the Unified Theory of Acceptance and Use of Technology (UTAUT) model from the Chinese perspective. Specifically, the region selected for this study from which the sample was drawn is the Fujian Province which is among the major provinces in southern China that implemented COVID-19 MCTA to manage, prevent, and control movement, detection, and spread of the virus. Though COVID-19 MCTA has contributed to curbing the spread of the virus through the effective identification of infected persons, there are still fundamental issues of security and privacy concerns that could hamper the wider acceptance of COVID-19 MCTA [20,21]. Moreover, the higher adoption rate of COVID-19 MCTA is crucial to attaining the full potential and effectiveness of COVID-19 MCTA [22]. Since the inception of COVID-19 MCTA, issues of security and privacy have been discussed and determined to influence user adoption [16,23], but these studies and the literature have not explored how security and privacy concerns can moderate the effect of the core UTAUT constructs such as performance expectancy (PE), facilitating conditions (FC), effort expectancy (EE), and social influence (SI) along with mobile self-efficacy (MSE) on the acceptance of COVID-19 MCTA. Hence this is the unique contribution of this paper to the literature which provides empirical evidence to examine whether security and privacy concerns related to COVID-19 MCTA have a negative moderating impact on the effect of these constructs (PE, FC, EE, SI, and MSE) on the individual user acceptance of COVID-19 MCTA. The UTAUT is considered the most robust and reliable model for technology adoption studies and it has been applied, integrated, and extended in diverse contexts, especially in understanding different types of users, organizations, technologies, tasks, etc. [24,25]. It offers better explanatory power as likened to other models in predicting the user intentions toward the utilization of new information technological systems like COVID-19 MCTA [26,27]. The research questions to be investigated are: 1) what are the factors driving the acceptance of COVID-19 pandemic mobile contact tracing apps? 2) To what extent do security and privacy concerns moderate the influence of these factors on the acceptance of the COVID-19 pandemic MCTA? Interrogating these research questions will provide policymakers, government, practitioners, and authorities responsible for COVID-19 control and management measures with the need to balance the priority of protecting people's lives against abusing the security and privacy concerns of users of COVID-19 MCTA not only in China but any parts of the world.

2. Research theoretical framework and proposed hypotheses

2.1. UTAUT

The Unified Theory of Acceptance and Use of Technology (UTAUT) is one of multiple theoretical models developed to elucidate the adoption and utilization of technological systems. The Unified Theory of Acceptance and Use of Technology (UTAUT) was created by Venkatesh, Morris [28] to forecast the acceptance and use of technology within organizations. However, it has since been applied to investigate the adoption of novel forms of information technology utilization in a variety of research fields. The UTAUT is considered a better alternative to other technology adoption models since it was integrated with other eight dominant models such Technology Acceptance Model [29], the Theory of Reasoned Action [30], the Motivational Model [31], Theory of Planned Behavior [32,33], Combined Technology Acceptance Model and Theory of planned behavior [34], Innovation Diffusion Theory [35], Social Cognitive Theory [36], and Model of PC Utilization [37]. Through analysis of data from four organizations, it was determined that the integration of these models into the Unified Theory of Acceptance and Use of Technology (UTAUT) accounted for 17–53 % of the variance in intention to use [28]. Despite this, UTAUT was found to surpass all eight models when utilizing the same data, which accounted for 70 % of the variability in behavioral intention and 50 % in technological system usage [28,38]. The moderators outlined in the UTAUT, namely gender, age, experience, and voluntariness, are crucial differentiating factors that set this model apart from others. As such, they play a crucial role in augmenting the predictive capabilities of the UTAUT [39], making it the most preferred for this study since it has been integrated with other well-noted models.

The UTAUT model has four main elements such as performance expectancy (PE), effort expectancy (EE), facilitation conditions (FC), and social influence (SI) that are instrumental in driving the intention and usage of information and mobile technology. The popularity of the UTAUT model can be witnessed in its wider application in many areas of study such as mobile tracing app adoption [40,41], e-government, and mobile government [42,43], Fintech and mobile/electronic commerce [44,45], mobile banking [46,47] and mobile health systems [48,49], etc. Specifically, research studies connecting UTAUT and COVID-19 studies have for instance indicated that the UTAUT constructs such as PE, FC, and SI are considered the paramount drivers of an individual's behavioral intention to embrace the use of digital technology in handling COVID-19 [50]. Another study confirmed that all the variables of the UTAUT were identified as highly influential determinants of the intention to adopt Zaka Technology services in the era of COVID-19 [51]. Also, it has been elaborated that the UTAUT constructs such as PE, and SI along with knowledge and trust in e-government showed a significant impact on the perpetual utilization of digital tax systems in the post-COVID-19 era, excerpt effort expectancy [52].

These extensive validations of the UTAUT model provide evidence of the robustness; reliability and validity of the UTAUT model and thus demonstrate the continued relevance of this model to enhance understanding of the influencers of technology adoption. Additionally, it presents a more dynamic predictive power as against other theories that delve into technology utilization. Consequently, this motivated the utilization of the UTAUT model as the theoretical foundation of this paper since it can better aid in unearthing the drivers of COVID-19 MCTA from the Chinese angle.

2.2. Hypotheses development

2.2.1. Performance expectancy (PE)

PE refers to the level at which individuals believe that using a particular system will enable them to achieve greater success in their work. It is widely regarded as the most influential factor in determining one's inclination towards adopting new technology [28]. The concept of PE encompasses the advantageous outcomes that technology yields for users, including its dependability, user-friendliness, suitability for work tasks, ability to motivate both internal and external stakeholders, comparative superiority over alternative solutions, as well as anticipated benefits from the implementation of new information systems [53,54]. Thus, the ability of COVID-19 MCTA to demonstrate higher beneficial (usefulness) outcomes concerning the reduction in reported COVID-19 cases, the discovery of new cases, and the prevention of the spread of the virus will inspire individuals to utilize the COVID-19 MCTA. Substantiated evidence has confirmed that the acceptance of technology is intricately linked to performance expectancy [55,56]. Consequently, H1 was proposed.

H1. PE is positively connected to the acceptance of COVID-19 pandemic MCTA.

2.2.2. Facilitating conditions (FC)

The concept of FC refers to the perception of individual users regarding the sufficient availability of organizational and technical systems to effectively utilize a specific system [28]. It concerns the removal of any technological and organizational barriers that will have a detrimental impact on the utilization of a technological system i.e. deprive users of getting the maximum benefits from such a system like the COVID-19 MCTA. FCs are thus the factors that will encourage individuals to use COVID-19 contract tracking systems on smartphones and tablets to aid in containing and mitigating the spread of the COVID-19 pandemic [57,58]. The use of COVID-19 mobile tracing apps will be based on sound technical infrastructure and organizational sources such as the availability of cheap mobile and broadband data, electricity, technical tutorials and quick feedback, uninterrupted power supply, higher internet connectivity, etc. Consequently, when people are convinced that there is available the required technical infrastructure and organizational support to encourage the adequate use of COVID-19 MCTA to minimize the spread and combat the virus will attract people to use them. The influence of FC on technology adoption has been validated by previous studies [59,60]. Accordingly, H2 was proposed.

H2. FC is positively connected to the acceptance of COVID-19 pandemic MCTA.

2.2.3. Effort expectancy (EE)

EE is the defining characteristic associated with the adoption of a new system [28]. Naturally, people will turn to adopt a technology they consider to be less complicated and hard to utilize. In the context of this study, EE refers to an individual's perception of the ease with which they can use the COVID-19 mobile contact tracing application (MCTA) i.e. the apps are free from mental and physical effort or difficulties [50,61]. Thus, COVID-19 mobile tracing apps that are developed with enhanced usability options, including convenient information/data download and upload capabilities, faster-browsing pages, noticeable messages/information, etc. will drive people to adopt COVID-19 apps. Research has demonstrated that EE is directly associated with the adoption behavior of technological systems [62,63]. H3 was thus put forward.

H3. EE is positively connected to the acceptance of COVID-19 pandemic MCTA.

2.2.4. Social influence (SI)

SI is defined as the individual user's perception that important people around them encourage the use of a technological system [28]. The perceptions of family, friends, and other key persons in society concerning their views and experiences concerning a system adoption can be instrumental in driving the acceptance of it among users. It has been elaborated that if people believe and are of the view that very important personalities (VIPs) use the COVID-19 app then they will also be driven to use it as well [55,64]. Social influence has been confirmed to drive the acceptance of technology [59,65]. Accordingly, H4 was proposed.

H4. SI is positively connected to the acceptance of COVID-19 pandemic MCTA.

2.2.5. Mobile self-efficacy (MSE)

Self-efficacy is considered as the awareness and confidence of people in their ability to manage and undertake a particular set of actions required to achieve a certain performance outcome [66]. In the realm of information systems, self-efficacy is considered crucial in the embracing of technological systems and the expected performance of such a technological system [67,68]. The demonstration of confidence by users in their ability to use COVID-19 MCTA could be instrumental in reducing the anxiety, challenge, and perceived risk associated with such a system. Mobile self-efficacy of COVID-19 MCTA is the individual user exhibition of confidence in their capability to use a mobile contact tracing technology system for COVID-19 to get the required information on COVID-19 to minimize the transmission of the COVID-19 pandemic. It thus follows that users with higher levels of confidence in their ability to operate a mobile technology system like COVID-19 MCTA will be more attracted to accept it. Numerous other studies have corroborated the existence of a positive correlation between mobile self-efficacy and technological system adoption [69,70]. Accordingly, H5 was proposed.

H5. MSE is positively connected to the acceptance of COVID-19 pandemic MCTA.

2.2.6. Security and privacy concerns (SPC)

Governments around the world in a collaborative attempt to reduce and contain the rapid transmission of the COVID-19 pandemic among the population developed COVID-19 MCTA to provide vital information and particularly track persons who might be infected [71,72]. China and South Korea are the two countries that have been very successful in the development and deployment of COVID-19 MCTA [73]. The contact tracing apps allowed governments to track people's movements (including places) as well as the locations of the virus [73,74]. This (COVID-19 pandemic MCTA) was considered by many as a good policy initiative toward combating the deadly pandemic but there have been severe privacy, security, and confidentiality concerns from both technology experts and users alike relating to the long-term consequences of COVID-19 MCTA [71,75]. The vulnerabilities and privacy concerns in mobile contact tracing apps put citizens at risk. It has been elucidated and emphasized that the uncertainty inherent in contact tracing apps along with their pre-existing privacy and security concerns could have a devastating impact on the public acceptance and utilization of this technology [71,76]. Security and privacy campaigners globally have warned of the dangers of mobile contact tracing systems and thus called for the implementation of strategic digital solutions that respect the citizens' privacy and security concerns [73]. It has been validated that privacy and security concerns relating to COVID-19 MCTA are negatively connected to the adoption behavior of mobile tracing apps [74]. However, in this paper, we are validating the moderating impact of security and privacy concerns on the relationship between PE, FC, EE, SI, MSE, and the acceptance of COVID-19 MCTA. Thus, it is projected that the privacy and security concerns related to COVID-19 MCTA will have a negative moderating impact on the interaction between PE, FC, EE, SI, MSE, and the acceptance of COVID-19 MCTA. Accordingly, H6, H7, H8, H9, and H10 were put forward.

H6. The relationship between performance expectancy and the acceptance of COVID-19 pandemic MCTA is moderated negatively by security and privacy concerns.

H7. The relationship between facilitating conditions and the acceptance of COVID-19 pandemic MCTA is moderated negatively by security and privacy concerns.

H8. The relationship between effort expectancy and the acceptance of COVID-19 pandemic MCTA is moderated negatively by security and privacy concerns.

H9. The relationship between social influence and the acceptance of COVID-19 pandemic MCTA is moderated negatively by security and privacy concerns.

H10. The relationship between mobile self-efficacy and the acceptance of COVID-19 pandemic MCTA is moderated negatively by security and privacy concerns.

3. Research model

The research model illustrated in Fig. 1 is based on the hypothesis developed from the previous section. The constructs of performance expectancy, facilitating conditions, effort expectancy, social influence, and mobile self-efficacy are presumed to drive the acceptance of COVID-19 pandemic MCTA. In addition, these relationships are moderated by security and privacy concerns.

4. Research methodology

The COVID-19 pandemic led to the development of MCTAs that were used in the tracking of infected persons and to reduce the transmission of the pandemic. However, the development of COVID-19 MCTA was heralded with security and privacy concerns. To appreciate the extent of the security and privacy concerns of the COVID-19 pandemic MCTA on individual adoption behavior a self-administered questionnaire was utilized to generate the required data to authenticate (research model shown in Fig. 1) which examines the influence of security and privacy concerns on the acceptance of COVID-19 MCTA among Chinese people within the Minhou County located in Fuzhou, Fujian Province. The items were picked from past literature but were converted to mirror the situation of this paper. The survey questions were derived from the literature as outlined below: performance expectancy, facilitating conditions, effort expectancy, and social influence [28,55], mobile self-efficacy [77], security and privacy concerns [74,78], and acceptance of mobile tracking apps [55]. The items were evaluated using a multi-item scale that utilized a five-point Likert scale, ranging from 1 = strongly disagree (SD) to 5 = strongly agree (SA). The multi-item scale measures are considered to be superior to a single-item scale, especially in ensuring higher reliability and validity of measured items [79,80]. The construct items used are shown in Table 1. The survey was divided into two components. The first component was about the constructs studied in the research model and the second component comprised of fundamental data regarding the participants, including their age, gender, and level of education.

The survey was translated from English to Chinese to ensure that Chinese-speaking respondents fully understood and appreciated the content and context of the questionnaire. The study pre-tested and piloted the questionnaire with 20 respondents to ensure successful data collection. This was done to warrant that the questionnaire was bereft of any vagueness that may undermine the respondents' capability to respond to the questions in the questionnaire [81,82]. The feedback we received from the pre-testing and piloting was useful in re-working and shaping some of the statements in the questionnaire for better clarity and comprehension. The outcome of the pre-testing and piloting was not part of the data analysis due to their small magnitude and inability to have a greater impact on the interpretation and conclusions of the paper.

The convenient sampling procedure was utilized to collect data from the target population who are teachers (teaching and non-teaching staff), and students from a University in the Southern (southeastern) part of China, and its environs at Minhou County located in Fuzhou City, the capital city of Fujian Province. Convenience sampling was utilized since it provides a cheaper and faster means to locate samples (respondents) that are easily accessible conveniently within the jurisdiction of the study [83,84]. Also, it is easy, affordable, saves time, and offers readily available subjects [85]. The questionnaire was first created online through an online questionnaire administration system (Wènjuàn xīng). We shared the link and QR code on social media systems (WeChat) via moments, group chats, and personal messaging. This research was approved on November 17, 2023, by the sub-academic committee of the School of Business Administration, Fujian Jiangxia University. Participants were informed that taking part in the study was a choice, and they could decide to leave at any point. Also, to ensure participants' privacy and confidentiality the data collection process was anonymous, and thus no identifying personal information was requested. The researchers collected data for approximately 2 months, from February to March 2023, and gathered a total of 214 valid responses. Consequently, the valid response collected was captured and used for the data analysis. We used SPSS statistical software to analyze the data. SPSS is widely used in dealing with complex

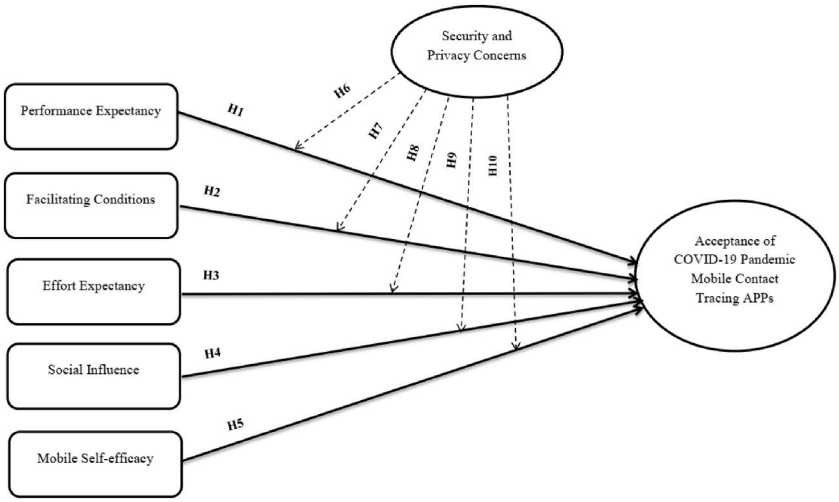

Fig. 1. Research model.

Table 1
Reliability and Convergent validity analysis.

Latent variable	Item and description		Non-standard factor loading	Standard factor loading	Standard error	T value	Cronbach's alpha	CR	AVE
Performance Expectancy	PE1	The use of COVID-19 mobile contact tracing apps will enhance my knowledge of the dangerous nature of the COVID-19 virus	1.000	0.912			0.936	0.955	0.875
	PE2	Mobile contact tracing apps for COVID-19 have the ability to lessen the spread of the COVID-19 virus	1.010	0.922	0.064	15.819[a]			
	PE3	I think COVID-19 mobile contact tracing apps are useful and effective in reducing pandemic risk in my life	1.123	0.972	0.061	18.452[a]			
Facilitating Conditions	FC1	I can use COVID-19 mobile contact tracing apps because I have internet access	1.000	0.869			0.914	0.927	0.810
	FC2	I can get help from experts to use COVID-19 mobile contact tracing apps	0.985	0.902	0.075	13.070[a]			
	FC3	I have the capabilities to use COVID-19 mobile contact tracing apps.	0.959	0.927	0.069	13.877[a]			
Effort Expectancy	EE1	I will find it easy to learn how to use COVID-19 mobile contact tracing apps.	1.000	0.986			0.931	0.978	0.938
	EE2	COVID-19 mobile contact tracing apps will be simple to use and easy to understand	0.932	0.944	0.037	25.397[a]			
	EE3	I can easily learn how to use COVID-19 mobile contact tracing apps because I have the necessary skills	0.969	0.974	0.029	33.792[a]			
Social Influence	SI1	People I value in my life suggest that I should use COVID-19 mobile contact tracing apps.	1.000	0.966			0.966	0.977	0.934
	SI2	People I trust recommend that I should utilize COVID-19 mobile contact tracing apps.	1.031	0.971	0.039	26.787[a]			
	SI3	My family and friends believe that I should use COVID-19 mobile contact tracing apps.	0.964	0.962	0.038	25.099[a]			
Mobile Self-efficacy	MSE1	I feel sure about using COVID-19 mobile contact tracing apps even if no one is there to show me how to use them	1.000	0.984			0.939	0.979	0.941
	MSE2	I can use COVID-19 mobile contact tracing apps even though I have never used them before.	0.981	0.947	0.038	25.648[a]			
	MSE3	If someone helps me get started, I can use COVID-19 mobile contact tracing apps	1.021	0.978	0.030	34.376[a]			
Security and Privacy Concerns	SPC1	I worry about my personal information's privacy when using COVID-19 mobile contact tracing apps	1.000	0.919			0.826	0.844	0.927
	SPC2	I care about the security settings of COVID-19 mobile contact tracing apps	1.013	0.965	0.085	6.288[a]			

(*continued on next page*)

Table 1 (*continued*)

Latent variable	Item and description		Non-standard factor loading	Standard factor loading	Standard error	T value	Cronbach's alpha	CR	AVE
	SPC3	I feel my privacy and security will be compromised when I use COVID-19 mobile contact tracing apps.	1.069	0.892	0.078	13.834[a]			
Acceptance of COVID-19 Pandemic Mobile Contact Tracing APPs	AMCTA1	I will accept the use of COVID-19 mobile contact tracing apps.	1.000	0.865			0.780	0.970	0.933
	AMCTA2	I always use COVID-19 mobile contact tracing apps	1.021	0.968	0.118	6.321[a]			
	AMCTA3	In the future, I plan to use mobile contact tracing apps for COVID-19	1.031	0.972	0.106	6.089[a]			

[a] $p < 0.001$.

research models [86,87]. Diverse rigorous statistical approaches such as common method bias, reliability, and validity analysis (i.e. Cronbach alpha, composite reliability, average variance extracted and discriminate validity, KMO and Bartlett's Test, rotated component matrix, statistical significance test via regression analysis) were used to validate our results to guarantee the accuracy and reliability of our findings.

4.1. Sample characteristics

The female respondents are 139 (65 %) and males 75 (35 %). The age distribution shows that 192 (89.7 %) of the respondents were between the ages of 18–25, 14 (6.5 %) between 26 and 30 years, and 8 (3.7 %) were above the age of 30 years. In terms of educational levels, 20 (9.3 %) were in junior college and below, 157 (73.4) had bachelor's degrees and 37 (17.3 %) were postgraduate degree holders (Masters and Ph.D.). The professional types show that 24 (11.2 %) were teaching and administrative staff, 186 (86.9 %) were students and 4 (1.9 %) had other professions. The conclusion that can be drawn from the sample characteristic of the study is that it is comprised of very youthful and well-educated respondents who may be comfortable with technology utilization and thus are better positioned to respond adequately to the research context and items that examined the influence of SPC of MCTA on the acceptance of COVID-19 pandemic MCTA.

4.2. Common methods bias (CMB)

Using only one survey instrument for both the independent and dependent data in a questionnaire can create bias due to relying on just one method of data collection [88,89]. CMB if not addressed can undermine the reliability and validity of the data used and the conclusions of the study. To check the likelihood of CMB in our data, the Harman single-factor analysis was used which states that if one single factor accounts for more than 50 % of the variance then CMV may be present in the data [90,91]. However, the results show that a single factor through the exploratory factor analysis explained 37.41 % of the variance, and therefore, we can conclude that the problem of CMB did not pose a challenge for this paper.

5. Results

5.1. Reliability and validity analysis

The researchers used SPSS to check how reliable and valid the factors studied in this research were. Factor loadings, composite

Table 2
Discriminant validity analysis.

Latent variable	PE	FC	EE	SI	MSE	SPC	AMCTA
PE	0.935						
FC	0.810***	**0.900**					
EE	0.766***	0.834***	**0.969**				
SI	0.589***	0.750***	0.589***	**0.966**			
MSE	0.668***	0.682***	0.767***	0.739***	**0.970**		
SPC	0.516***	0.474***	0.485***	0.350***	0.482***	**0.962**	
AMCTA	0.536***	0.636***	0.570***	0.598***	0.518***	0.716***	**0.966**

The bold above the diagonal is the square root of the AVE. ***$p < 0.001$.

reliability, Cronbach alpha, and average variance extracted were used to assess the reliability and convergent validity of the measures (shown in Table 1). Experts suggest that values higher than 0.70 are ideal for factor loadings, composite reliability, and Cronbach alpha [92]. The average variance extracted (AVE) is suggested to have a threshold value of 0.50 [93,94]. As indicated in Table 1, all the threshold standard values for each of the quality indicators such as factor loadings, composite reliability, Cronbach alpha, and average variance extracted have been met and thus an indication of the assurance of the reliability and validity of the measures. Additionally, discriminate validity was conducted to evaluate the construct validity of the items based on the principle (Fornell-Larcker criterion i.e. the square of the average variance extracted should be higher than the correlation between the construct and other constructs) of Fornell and Larcker [95]. From the discriminant validity in Table 2, it can be seen that there is a positive correlation among the variables. The largest correlation coefficient between the studied constructs is 0.810 (between PE and FC). Table 2 also demonstrates that the square root of the AVE value above the diagonal is greater than the correlative coefficient between the dimensions below the diagonal, indicating that the scale has good discrimination validity.

Furthermore, the exploratory factor analysis (Table 3) shows that the KMO is equal to 0.960, greater than 0.70 and the significance of Bartlett's test is less than 0.001 which is less than 0.05 and thus an illustration that the scale used in this study is appropriate for the analysis of the factors. Additionally, the exploratory factor analysis of the rotated component matrix (Table 4) shows that the maximum factor loading for each item is on the common construct which is an indication that the scale utilized is good i.e. the validity result is good.

5.2. Analysis of model

The analysis of the model was done using SPSS to test hierarchical regression analysis (Table 5). The results (direct effect) of Model 4 to Model 8 show that performance expectancy ($\beta = 0.616$, $p < 0.01$), facilitation conditions ($\beta = 0.529$, $p < 0.01$), effort expectancy ($\beta = 0.374$, $p < 0.01$) social influence ($\beta = 0.510$, $p < 0.01$) and mobile self-efficacy ($\beta = 0.238$, $p < 0.05$) were all significant predictor of the acceptance of COVID-19 pandemic MCTA. Thus, H1, H2, H3, H4 and H5 were supported statistically.

To test H6-H10, this article uses the GLM model to verify the moderating effect of security and privacy concerns through hierarchical regression analysis. The specific steps of hierarchical regression analysis are as follows: First, only control variables are added (as shown in Table 5, Model 1), observe the impact of relevant control variables; secondly, add control variables and independent variables (as shown in Table 5, Model 2), and observe the joint impact; thirdly, add control variables, independent variables and adjusting variables (as shown in Table 5, Model 3), observe the possible influence of the adjusting variable itself; finally, five different regression models are constructed based on the five independent variables, and control variables, independent variables, adjusted variables, and the cross-product term of the independent variable and the adjusted variables (such as Table 5, Model 4-Model 8), observe the role of the moderation effect.

Furthermore, the moderating effect analysis (Table 5) shows that all the indirect effects were supported. Specifically, it can be seen that the interaction between performance expectancy and security and privacy concerns is significant ($\beta = 0.488$, $p < 0.01$) which is indicative of the moderating effect of security and privacy concerns between performance expectancy and acceptance of COVID-19 pandemic MCTA (See Fig. 2). H6 was therefore supported. Again it can be seen that the interaction between security and privacy concerns and facilitating conditions was significant ($\beta = 0.329$, $p < 0.05$) which means that security and privacy concerns play a significant and positive role in moderating the interaction between facilitating conditions and acceptance of COVID-19 mobile tracing apps (See Fig. 3). H7 was consequently, supported.

Additionally, the interaction between effort expectancy and SPC was significant ($\beta = 0.243$, $p < 0.01$), indicating that security and privacy concerns are significant in moderating the impact of EE on acceptance of the COVID-19 pandemic MCTA (see Fig. 4). H8 was accordingly supported. Furthermore, the interaction between social influence and SPC was significant ($\beta = 0.173$, $p < 0.05$), indicating that security and privacy concerns significantly moderate the influence of social influence on the acceptance of COVID-19 pandemic MCTA (See Fig. 5). H9 was also supported. Finally, it can be observed that the interaction between mobile self-efficacy and SPC was significant ($\beta = 0.160$, $p < 0.05$), illustrating that security and privacy concerns play a significant moderating role in the relationship between mobile self-efficacy and acceptance of COVID-19 pandemic mobile tracing apps (See Fig. 6). Accordingly, H10 was statistically supported.

6. Discussions

The timely innovative introduction of the COVID-19 pandemic MCTA was instrumental in identifying persons who could have the COVID-19 virus through contact tracing persons they have come in contact with and their location as well which ultimately contributed to reducing the rate at which infections are spreading. The wider acceptance of COVID-19 pandemic MCTA was a major contributive factor to the effectiveness of mobile contact tracing systems during the pandemic. This paper examined the factors that

Table 3
KMO and Bartlett's test.

Kaiser–Meyer–Olkin measure of sampling adequacy		0.923
Bartlett's test	Approx. chi-square	5069.511
	Df	210
	Sig.	0.000

Table 4
Rotated component matrix.

Item	Factor1	Factor2	Factor3	Factor4	Factor5	Factor6	Factor7
PE1	0.811						
PE2	0.794						
PE3	0.817						
FC1		0.669					
FC2		0.645					
FC3		0.615					
EE1			0.746				
EE2			0.754				
EE3			0.775				
SI1				0.852			
SI2				0.824			
SI3				0.836			
MSE1					0.772		
MSE2					0.769		
MSE3					0.776		
SPC1						0.922	
SPC2						0.713	
SPC3						0.910	
AMCTA1							0.887
AMCTA2							0.696
AMCTA3							0.827

Varimax is used.

drive the acceptance of COVID-19 pandemic MCTA under the influence of security and privacy concerns based on a modified UTAUT model. The analysis of the data has shown that all the hypothesized relationships are statistically supported. Specifically, the study has demonstrated that key constructs of the UTAUT such as PE, FC, EE, and SI along with MSE were significant determinants of the acceptance of COVID-19 pandemic MCTA. The study further confirmed that SPC related to COVID-19 MCTA showed a negative moderating impact on the relationship between PE, FC, EE, SI, MSE, and the acceptance of COVID-19 pandemic MCTA.

The significant influence of PE on the acceptance of COVID-19 MCTA is a demonstration that if users of the apps are convinced that COVID-19 app can provide useful information and data regarding the pandemic and reduce exposure to the virus, limit the wider spreading of the virus then the individual will be attracted to accept the use of COVID-19 MCTA. The COVID-19 MCTA benefits should be made sufficiently clear to users of the app with integrated values schemes that can give updated information about the virus on how, where, and when they can be tested. The direct impact of PE on the use of COVID-19 MCTA is consistent with other studies that have revealed that improving the PE of COVID-19 MCTA can drive its wider acceptance [55,59].

Furthermore, the validated impact of FC on the acceptance of COVID-19 pandemic MCTA implies that government and health authorities should ensure that there is an adequate managerial and technological infrastructure to support individual user adoption and utilization of COVID-19 pandemic MCTA. These managerial and technical supports may include adequate help and tutorial functions, good internet connectivity, lower cost of internet bundles, mobile handsets, etc. When users are empowered by these facilitating conditions they will accept the use of COVID-19 MCTA. This discovery backs research that has also found a strong connection between FC and the adoption of COVID-19 MCTA [22,74].

Additionally, the confirmation of the direct impact of effort expectancy on the acceptance of COVID-19 MCTA is a call for the development of MCTA that will be user-friendly and with easy-to-operate features. The apps should be easily downloadable and stalled without difficulty along with smooth navigation of apps pages and easy upload of information into the apps. Particularly for those who are not technologically inclined towards the use of mobile apps, the design and development of COVID-19 MCTA that are easy to use will be a contributive factor that can encourage them to use COVID-19 MCTA. The result is in agreement with studies that have illustrated that the EE associated with technology drives its adoption [58,96]. However, this differs from previous studies that demonstrated that the level of EE associated with COVID-19 MCTA does not influence its adoption [74,97].

Also, the study's validation of the direct influence of SI on the individual acceptance of COVID-19 MCTA illustrates the impact that close friends, relatives/family, and important key personalities can have on the diffusion and use of a technological system such as COVID-19 MCTA. Mobile app developers should use the influence of family, friends, and VIPs to convince users of the personal and societal advantages they will receive when they use COVID-19 MCTA, particularly in protecting their loved ones, family, and friends from the deadly virus. Thus, the power inherent in the factor of social influence can be utilized to recruit new users to use the apps and this can drive a wider acceptance of the COVID-19 apps to help curb the increasing rate of COVID-19 infections. This finding supports other previous research that showed that social influence can potentially encourage the use of COVID-19 pandemic MCTA [41,98].

Furthermore, the paper's confirmed direct significant impact of mobile self-efficacy on the acceptance of COVID-19 MCTA is a strong testament that users who demonstrate higher levels of self-efficacy towards their ability to use mobile apps can be fundamental to the usage of COVID-19 MCTA. Mobile apps cannot be used by users to access information and data (for instance COVID-19 information), content, and entertainment tasks if the individual mobile self-efficacy is very low. Through education and awareness creation, users can improve their level of confidence, attitudes, and self-efficacy towards the use of any mobile app such as COVID-19 MCTA. The finding is corroborated by other studies that showed that individual self-efficacy concerning a technology influences their

Table 5
Results of regression analysis.

Variable types	Acceptance of COVID-19 Pandemic Mobile Contact Tracing APPs							
	Model1	**Model2**	**Model3**	**Model4**	**Model5**	**Model6**	**Model7**	**Model8**
Control variable								
Sex	−0.048	−0.017	−0.006	−0.026	−0.045	−0.045	−0.026	−0.035
	(−0.702)	(−0.346)	(−0.161)	(−0.608)	(−1.057)	(−0.978)	(−0.642)	(−0.749)
Age	0.125*	0.033 (0.063)	0.016 (0.392)	0.152***	0.089**	0.118**	0.044	0.109**
	(1.822)			(3.488)	(2.076)	(2.581)	(1.072)	(2.321)
Education	0.089	−0.037	0.037 (0.870)	0.088*	0.109**	0.172***	0.057	0.144***
	(1.228)	(−0.665)		(1.839)	(2.310)	(3.547)	(1.187)	(2.755)
Job	0.006	0.115**	0.063 (1.567)	−0.048	0.005	−0.021	0.024	−0.038
	(0.081)	(2.211)		(−1.030)	(0.118)	(−0.434)	(0.547)	(−0.745)
Independent variable								
Performance Expectancy		0.256***	0.105 (1.548)	0.616***				
		(2.940)		(5.222)				
Facilitating Conditions		−0.038	0.067 (0.835)		0.529***			
		(−0.363)			(4.612)			
Effort Expectancy		0.162 (1.164)	0.014 (0.181)			0.374***		
						(2.905)		
Social Influence		0.769***	0.655***				0.510***	
		(7.006)	(7.710)				(5.216)	
Mobile Self-efficacy		−0.426***	−0.454***					0.238**
		(−4.233)	(−5.863)					(2.022)
Moderator variable								
Security and Privacy Concerns			0.543***	0.812***	0.758***	0.732***	0.622***	0.738***
			(11.912)	(8.078)	(7.663)	(7.009)	(6.396)	(7.055)
Interaction								
Performance Expectancy × Security and Privacy Concerns				0.488***				
				(2.814)				
Facilitating Conditions × Security and Privacy Concerns					0.329**			
					(1.972)			
Effort Expectancy × Security and Privacy Concerns						0.243***		
						(2.196)		
Social Influence × Security and Privacy Concerns							0.173**	
							(1.997)	
Mobile Self-efficacy × Security and Privacy Concerns								0.160**
								(1.981)
R2	0.024	0.526	0.721	0.629	0.632	0.582	0.661	0.560
△R2	0.006	0.505	0.707	0.616	0.619	0.568	0.649	0.545
F-value	1.298	25.140***	52.446***	49.896***	50.467***	41.025***	57.301***	37.428***

*p < 0.1; **p < 0.05; ***p < 0.01.

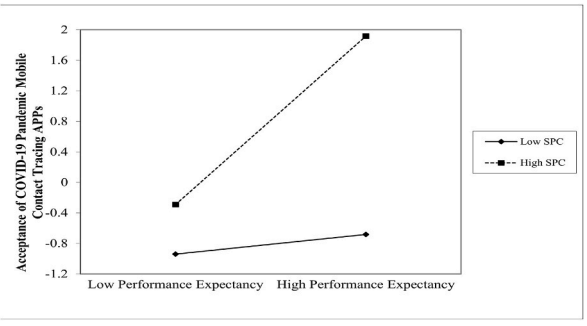

Fig. 2. A line chart of the moderating effect of security and privacy between performance expectancy and acceptance of COVID-19 pandemic MCTA.

acceptance of such technology (like m-health apps) [96,99].

Finally, the study's validation of the negative moderating impact of SPC on the effect of PE, FC, EE, SI, and MSE, on the acceptance of COVID-19 MCTA is a demonstration that the individual users' privacy and security concerns when not addressed can deflate the impact of PE, FC, EE, SI, and MSE on the adoption of COVID-19 MCTA. This implies that in the design and development of COVID-19 MCTA, the privacy and security of these apps should be a top priority. The COVID-19 MCTA should improve the fortification of users'

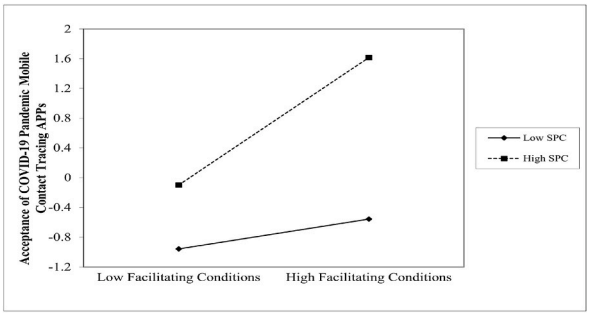

Fig. 3. A line chart of the moderating effect of security and privacy between facilitating conditions and acceptance of COVID-19 pandemic MCTA.

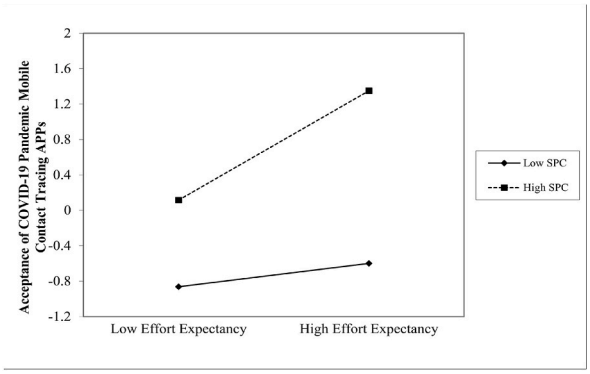

Fig. 4. A line chart of the moderating effect of security and privacy between effort expectancy and acceptance of COVID-19 pandemic MCTA.

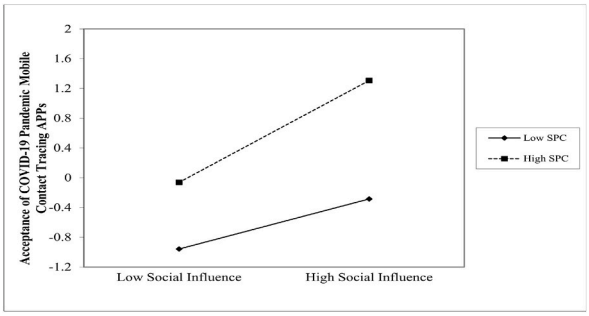

Fig. 5. A line chart of the moderating effect of security and privacy between social influence and acceptance of COVID-19 pandemic MCTA.

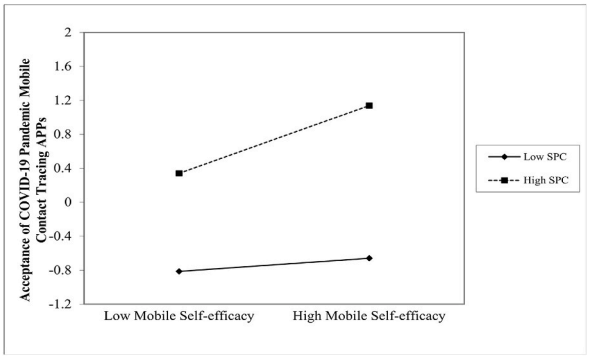

Fig. 6. A line chart of the moderating effect of security and privacy between mobile self-efficacy and acceptance of COVID-19 pandemic MCTA.

personal information and data from any unwarranted third party without their due consent. Particularly, given the sensitive nature of the COVID-19 infection and the social isolation that it brings along with its psychological impact on individuals, the violation of the privacy and security of MCTA that breach the release of COVID-19 personal information/data destroys their willingness to engage in the use of COVID-19 mobile apps through these important variables such PE, FC, EE, SI, and MSE. Developers of mobile contact tracing apps must provide clarity on how they intend to use the data collected along with the tailored services and information provided. Individuals should be adequately informed about the security and privacy policy options for them to decide whether to accept or not. These findings could not be related to any past or current study since no study to the best of our knowledge has validated the moderated influence of privacy and security concerns on the relationship between PE, FC, EE, SI, MSE, and acceptance COVID-19 pandemic MCTA. These are thus the major contributions of this paper to the literature on mobile technology adoption relating to the acceptance of the COVID-19 pandemic MCTA.

6.1. Theoretical implications

The findings of the paper contribute to the existing literature on mobile technology adoption relating to COVID-19 MCTA and provide theoretical implications for researchers i.e. the modified and extended UTAUT with mobile self-efficacy and privacy and security concerns along with the key constructs of UTAUT such as PE, FC, EE, and SI. The validated moderated impact of security and privacy concerns on the interaction between PE, FC, EE, SI, MSE, and acceptance of COVID-19 MCTA is the major contribution and novelty of this paper which is distinguishable from other papers. While studies have established the direct influence of app-related privacy concerns on the behavioral intention to use contact tracing apps [61,74], they, however, failed to examine how security and privacy concerns moderate the impact of the four key constructs of the UTAUT model along with mobile self-efficacy on the acceptance of COVID-19 pandemic MCTA.

6.2. Practical implications

There are several managerial implications of this research for policymakers, governments, health practitioners in charge COVID-19 pandemic, and mobile contact tracing app developers when it comes to the development and diffusion of COVID-19 MCTA to detect and curb the spread of the pandemic. First, COVID-19 mobile tracing apps should be designed to achieve efficiency and higher performance expectancy for users in terms of the provision of relevant and timely information about the virus, especially in locating people infected around them. Secondly, in places that are badly affected by COVID-19 restrictions and lockdowns, governments can provide some relief packages to support and facilitate the use of COVID-19 MCTA. These facilitating conditions for areas severely affected could be in the form of reduced cost of mobile handset and data or provision of free mobile data and if possible the provision of a cluster of Wi-Fi hotspots particularly for deprived cities and villages and constant supply of electricity etc.

Thirdly, COVID-19 mobile tracing apps should be developed with less complicated functions and features, especially in regions and places where there are more aged persons who might not be acquainted with mobile app utilization. That is the ease of use and user-friendly features of mobile contact tracing apps should be of priority if the apps are to serve their ultimate purpose of locating infected persons and reducing the rate of infections among people. Fourthly, social media features/technology could be infused into the development of COVID-19 mobile contact tracing apps so that people can easily recommend and share the apps with their friends and family members and thus can achieve faster utilization among the people. Important influential brands and high-profile personalities like celebrities, filmmakers, TV stars, sportsmen, etc. should be encouraged to partner with relevant authorities to promote information on the use of COVID-19 MCTA. These campaigns can be used to share vital information on the security and privacy mechanisms and the personal and societal benefits that the use of the apps can generate. Also, to enhance the mobile self-efficacy of users, especially in deprived places with more elderly persons, a broader strategic publicity and awareness drive can be undertaken to educate people on how to use mobile tracing apps and this can be done through TV and radio stations. Social media systems can be utilized to educate and empower users' self-efficacy of mobile tracing app usage i.e. features and operations.

Fifth, individual user SPC should be incorporated into the development of COVID-19 MCTA. Mobile app developers can integrate the use of blockchain, encryption, and anonymization solutions to protect users' security and privacy relating to the COVID-19 personal information provided on tracing apps. Blockchain technology is considered a non-regional and transparent technology that provides better access protocols for COVID-19 MCTA. Also, it ensures effective control mechanisms to help prevent users from intentional misinformation and abuse by unwarranted third parties. COVID-19 MCTA that stores users' data based on weaker encryption control systems should be avoided and rather data on COVID-19 apps should be encrypted with secured cryptographic encryption algorithms such as symmetric and asymmetric encryption keys based on two major encryption standards such as Advanced Encryption standards and, Data Encryption standards.

Furthermore, cloud security could be deployed for mobile contact tracing apps to ensure that security and privacy policies, technologies, and control systems are adequately implemented to safeguard COVID-19 MCTA data and its related applications. This can prevent known vulnerabilities in fingerprinting and user identity tracking concerning COVID-19 pandemic data and information disclosure. Finally, government intervention through national data protection authorities is needed in the development of user security and privacy policies concerning the development of the COVID-19 pandemic MCTA to ensure that: mobile contact tracing apps are properly approved, accountable, and in compliance with national personal data protection regulations; individual users are in maximum control of personal data and that apps installation should be voluntary with the option to discontinued if no longer required; use of personal data is limited only to relevant reasons and should not include location tracking; tight limitations on storage so that personal data should not be stored longer than required; and finally maximum security of data that permits storage of individual data

on user's device and encrypted.

7. Conclusions

This paper examined the drivers of the acceptance of COVID-19 pandemic MCTAs based on the modified UTAUT framework. Several COVID-19 MCTAs have been developed since the COVID-19 pandemic emerged but the individual user SPC of these MCTAs has been called into question. Consequently, the acceptance of COVID-19 mobile tracing based on the core UTAUT constructs (PE, FC, EE, and SI) and MSE under the influence of security and privacy concerns were interrogated. The findings have revealed that PE, FC, EE, SI, and MSE are significant drivers of individual user acceptance of COVID-19 MCTA. SPC of COVID-19 MCTA was found to moderate negatively the influence of PE, FC, EE, SI, and MSE on the user acceptance of COVID-19 MCTA. These findings have provided insightful managerial implications for policymakers and authorities in charge of COVID-19 prevention and control measures to design strategic COVID-19 MCTA that address the security and privacy concerns of users. This is vital if the fight against the COVID-19 pandemic is to be won locally and internationally. Additionally, the following recommendations are made to empower governments and local authorities in dealing with any future pandemic emergency:

a) Governments and national emergency response centers or commissions should not jeopardize or downplay the need to protect individual security and privacy concerns over the urgency to tackle a pandemic spread.
b) During national pandemic emergencies, governments and steering committees should provide free or subsidized technology-driven relief items such as mobile handsets, internet connectivity, etc. to affected communities or people, especially in deprived regions/cities on time to enhance information collection and prompt mobile contact tracing.
c) Mobile contact tracing apps should be designed with less complicated functionality for easy usage among people especially those with less technological know-how.
d) Mobile app developers or experts should integrate social media features into mobile contacting tracing apps to help better in fighting any future pandemic.

8. Limitations and future research

First, since the COVID-19 pandemic MCTAs are not the same across the board and the data generated was from the Chinese perspective, the interpretation and generalization of the results and conclusions should be done with care. Secondly, the model and methodological approach utilized in this paper may be replicated in other jurisdictions but the results and conclusions drawn might not be supportive of the findings of this paper. Thirdly, not all the drivers of the acceptance of COVID-19 MCTA were fully covered in this paper, and thus it is recommended that future works be carried out with an expanded (larger) sample size. Possible future works may examine how the technological, organizational, and environmental (TOE) framework along with trust in government integrated into UTAUT can elucidate the user adoption of COVID-19 MCTA.

CRediT authorship contribution statement

Isaac Kofi Mensah: Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Tianyu Zhao:** Validation, Investigation, Funding acquisition, Formal analysis, Data curation.

Data availability statement

Data will be made available on request.

Ethics statement

Studies involving human participants were reviewed and approved by Fujian Jiangxia University's Academic Subcommittee of the School of Business Administration (November 17, 2023). Informed consent was obtained from all subjects involved in the study.

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Declaration of competing interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e39086.

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