Article

Understanding smallholder farmers' intention to adopt agricultural apps: the role of mastery-approach and innovation hubs

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Abstract: While current studies have focused on adoption and the relevant content of the app to become a decision support system, very few studies have focused on the farmer's intention and initial decision to adopt. Based on a survey of 394 smallholder farmers this study investigated Mexican farmers' willingness to adopt an agricultural advice app. A Structural Equation Modelling approach, based on the Unified Theory of Acceptance and Use of Technology (UTAUT) was applied. To understand farmers' adoption decision, extended constructs were studied (e.g. mastery-approach goals) along with farmers' age and participation in an innovation hub. Results showed that the intention to adopt the app is predicted by how farmers believe that technical infrastructure exists and by the expectation of the farmers using the app to acquire new knowledge. The multi-group analysis revealed that performance expectancy is a relevant predictor of the intention to adopt, whereas the mastery-approach goal is relevant only for younger and farmers not connected to the innovation hub. The results may well be a baseline to research further suitable non-financial incentives for different farmers' groups, then encourage initial adoption and enhance uptake. The findings are useful for practitioners and app developers designing digital decision support tools.

Keywords: structural equation modelling; smallholder farmers; smartphone apps; decision support systems; unified theory of acceptance and use of technology; innovation hubs; mastery-approach goal

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1. Introduction

Smartphone applications can provide farmers with easy access to tailor-made relevant information to inform their decisions for increasing crop yields, protecting their land and water resources and improving their livelihoods [1,2]. The adoption of mobile phone technologies by farmers also holds the promise of the collection of more comprehensive, relevant, and accurate agricultural data [3,4]. Moreover, crowdsourcing and Citizen Science applications are offering solutions for simultaneously offer affordable decision support systems (DSS) to smallholder farmers while collecting agricultural data [5,6]. However, uptake by farmers and advisers of DSS and mobile phone apps are still somehow low [7]. Among others, challenges of low uptake relates to financial barriers, infrastructure, gaps among developers and end-user information needs, and lack of understanding of farmers' profiles in the local context [7–9]. Previous recommendations to effectively DSS design and delivery are found in academic literature in the UK [7] or generated by private consortiums such as the GSMA mAgri Design Toolkit for developing countries

[10]. However, other geographical regions and realities similar to rural areas in Central and Latin America remains understudied [11].

Moreover, where adoption does occur, not all farmers adopt Information and Communication Technologies (ICTs) in the same manner [12] nor are farmers' motivations the same in all settings [6]. While current studies have focused on smartphone adoption by farmers in African countries [13,14] and on advice-delivery tools for smallholder farmers in India [15]; only few have focused on the initial adoption decision. The drivers of farmers' initial adoption of agricultural information apps are less studied than those of apps offering financing or health services [16]. Exceptions are a study which looked at the initial adoption of smartphone apps for crop protection in Germany, however more research is needed in developing and emerging countries [11]. Therefore, we investigate the factors affecting the initial uptake of an agricultural app by Mexican smallholder farmers. This is highly relevant because Mexico is a region with viable ecosystem of ICT innovations in the agricultural sector due to mobile phone apps being developed by government agencies to connect farmers with buyers or get advice on crops production. As well, B-corporations such as the Extensio platform (Esoko before) were launched in 2015 to provide content to Mexican farmers through SMS, a call centre and a smartphone app. Furthermore, reflecting on the extension experience and large datasets of the International Maize and Wheat Improvement Center (CIMMYT), the AgroTutor app is a mobile phone app that provides information to smallholder farmers about maize and wheat and related topics, including weather, grain and input prices, benchmarking, agronomic recommendations and potential yield [17].

To gain a better understanding of farmers' initial adoption decision, this study applied the Unified Theory of Acceptance and Use of Technology (UTAUT) introduced by Venkatesh et al. (2003). The UTAUT considers the behavioral factors "performance expectancy" (PE), "effort expectancy" (EE), "social influence" (SI) and "facilitating conditions" (FC). Based on a fieldwork survey conducted in 2019 with 394 farmers, the model for the UTAUT is estimated using structural equation modelling (SEM). The novelty of this article is twofold. Firstly, this is the first study explicitly focusing on smallholder farmers' initial adoption decision of an agricultural app in Mexico. Specifically, this study adds to the literature by examining if the UTAUT framework enriched with additional constructs (personal innovativeness in IT & mastery-approach goals) can contribute to the understanding of the underlying behavioural factors influencing the initial preparedness and initial adoption decision of small-scale farmers. In this way we are able to explore the effect of smallholder farmers' motivation to learn and explore new technologies and their perception of the app during the initial decision to adopt. Extending the UTAUT constructs offers two interesting notions: (i) a baseline of farmers' intrinsic motivation ('why' are they motivated to use it); and (ii) behavioural factors influencing the intention to adopt ('how' is the app being perceived). Secondly, this is the first study considering the role of 'connectedness to an innovation hub' in the farmers' intention to adopt a smartphone app developed by a non-profit research-for-development organization (vs. commercial for-profit apps). The results are of interest for decision makers in digitalization, app developers, project managers and provide insights on ways of encouraging adoption of agricultural apps.

2. Theoretical framework and research model

The Unified Theory of Acceptance and Use of Technology (UTAUT) aims to explain usage behavior such as the intention to adopt a mobile phone app [18]; and has been empirically validated in diverse disciplines [19]. It is the theoretical basis for the present work. The model is based on eight prominent user adoption models and was later extended into the UTAUT2 by adding three constructs (hedonic motivation, price value and habit) [20]. However, UTAUT2 constructs are not included in this work since the focus is on the initial adoption rather than actual use. The hypotheses concerning the relationships between the proposed factors of the farmers' behavioural intention (BI) are outlined below (Fig. 1):

"Performance expectancy" is the degree to which using a technology will provide benefits to individuals using it [18]. In this study, it refers to the degree to which a farmer believes that accessing agriculture-related information through a mobile phone app will benefit her/his farming activities. One attractive feature of an agricultural app is farmers' ability to access accurate local information anywhere, at any time, without wasting productive time. Therefore, we hypothesized that:

H1: Performance expectancy (PE) positively affects behavioral intention (BI) to use a mobile phone app.

"Facilitating conditions" refers to the extent to which farmers believe that technical infrastructure exists to help them to use a technology whenever necessary [20]. Using a mobile phone app requires certain skills, such as being able to operate a mobile phone, download the app, and navigate the content. A farmer who shares a household with an educated person or has access to facilitating conditions, such financial resources, will have a greater intention to use. Therefore, we hypothesized that:

H2: Facilitating conditions (FC) positively affect behavioral intention (BI) to use a mobile phone app.

"Effort expectancy" is the degree of ease associated with farmers' use of a technology [20]. In the case of an app, some farmers might be more literate than others in ICT-based technologies and would accordingly be expected to have fewer problems using a mobile phone to access agricultural or crop information. It is expected that farmers who are easily able to obtain and interpret relevant information using a mobile phone app would be more willing to use it and therefore we hypothesized that:

H3: Effort expectancy (EF) positively affects behavioral intention (BI) to use a mobile phone app.

"Social influence" is the extent to which farmers perceive that important people believe they should use a particular technology [20] such as a mobile phone app. The primary assumption is that individuals tend to consult their social network, especially friends and family, about new technologies and can be influenced by perceived social pressure of important people. It might be particularly important to explain an initial adoption [21]. Therefore, we hypothesized that:

H4: Social influence (SI) positively affects behavioral intention (BI) to use a mobile phone app.

Additional constructs: personal innovativeness in IT, mastery-approach goals, and trust

In this study additional constructs, the mastery-approach goal orientation (MAG) and personal innovativeness in information technology (IN) extend the reach of UTAUT for assessing farmers' intention to start using an app. Such intrinsic motivations were found suitable as they can provide a baseline to explore 'why' farmers might be motivated to use an app based on their incentive to learn and master something. Researchers have recently suggested "attitude" as a mediator of the intention to adopt [22]. However, MAG and IN are specific to IT technologies and suitable for the case of an agricultural app aiming at exchange of information. In the following paragraphs a detailed description of the theories in which the constructs are based as well as the rationale to select them in the present model is presented.

Diffusion of Innovation Theory (DIT) is an extensive social and psychological notion that tries to predict how individuals make decisions to adopt a new innovation [23,24]. The concept was adapted by [25] and proposed a new construct to measure personal innovativeness as "the willingness of an individual to try out any new IT." Since farmers participating in the current study do not have experience in using this specific mobile phone app, we've have included the IN construct in our model (Fig. 1). Moreover, it is well-known from the DIT that highly innovative individuals actively seek information about new technologies or ideas. They are able to cope with high levels of uncertainty and are more favourably inclined to accept a technology [23]. This leads to the following hypothesis:

H5: Personal innovativeness in information technology (IN) positively affects behavioral intention (BI) to use a mobile phone app.

Even though trust can be understood as a subjective belief, its effect as a construct on behavioral intention has gained support in the context of UTAUT and mobile payments (m-payments) explored along with risk [26–29]. In contrast with [30], this work explored trust concerning the app provider (or promoter) rather than trust in the tool or project. Then trust (TR) is defined as the extent to which the mobile phone app provider(s) is believed to want to do good for the farmer, apart from selfish motives. If a farmer believes the mobile phone app promoters (e.g. extension agent) care about his/her interests, the mobile phone app provider is seen as displaying benevolence toward the farmer [31]. The probability of farmers' sharing their agronomic information is highly dependent on the trustworthiness of the party (i.e., "trustees" such as agronomic experts, researchers, and research institutes). Hence, we formulated the following hypothesis:

H6: Trust (TR) positively affects behavioral intention (BI) to use a mobile phone app.

As most farmers do not have experience with the use of these type of mobile phone apps, experience was not included as a moderator. Instead, we hypothesize that the connection with the innovation hub brokered by CIMMYT in Guanajuato (Section 3.1), moderates the effects of UTAUT constructs and additional constructs due to the development of a conducive environment for innovation and decision making. The trust construct along with the connectedness to an innovation hub moderator variable are used to add the role of the extension services in providers and disseminators of the app technology and to explore in general the enabling environment in which an app is being developed and pilot-tested to target early adopters.

Lastly, the MAG is based on the Goal Orientation Theory which articulates that the main goal people can pursue while performing a task is that of mastery [32], and to understand something new or to improve their level of know-how [33]. The MAG has been extensively explored in the context of learning and education [34]. The livelihoods of most smallholder farmers depend on farming, so they will always look for ways, skills and knowledge to improve agricultural productivity. Farmers with a mastery goal will be expected to use the mobile phone app to acquire new skills and knowledge, leading to the following hypothesis:

H7: A mastery goal orientation positively affects behavioral intention (BI) to use a mobile phone app.

In addition, sociopsychological research relates farmers' intrinsic motivation to the decision to participate in extension/education activities such as motivational orientation [35]. This is an interesting proposition to explore the links between farmer motivation to learn and explore new technologies and the (farmer's perception of the) app as such and its context.

We hypothesize that age moderates the effects of UTAUT constructs (PE, EE, SI, FC) on behavioral intention [18,36]. The effect of effort expectancy (EE) and facilitating conditions (FC) on behavioral intention are expected to be stronger for older farmers. The effect of performance expectancy (PE) is expected to be stronger for younger farmers. Lastly, the effect of social influence (SI) is expected to be stronger for older and experienced farmers. The added constructs (IN, TR, MAG) could also be influenced by age and connection to an innovation hub, but only MAG was included in the multi-group analysis, as we explain below.

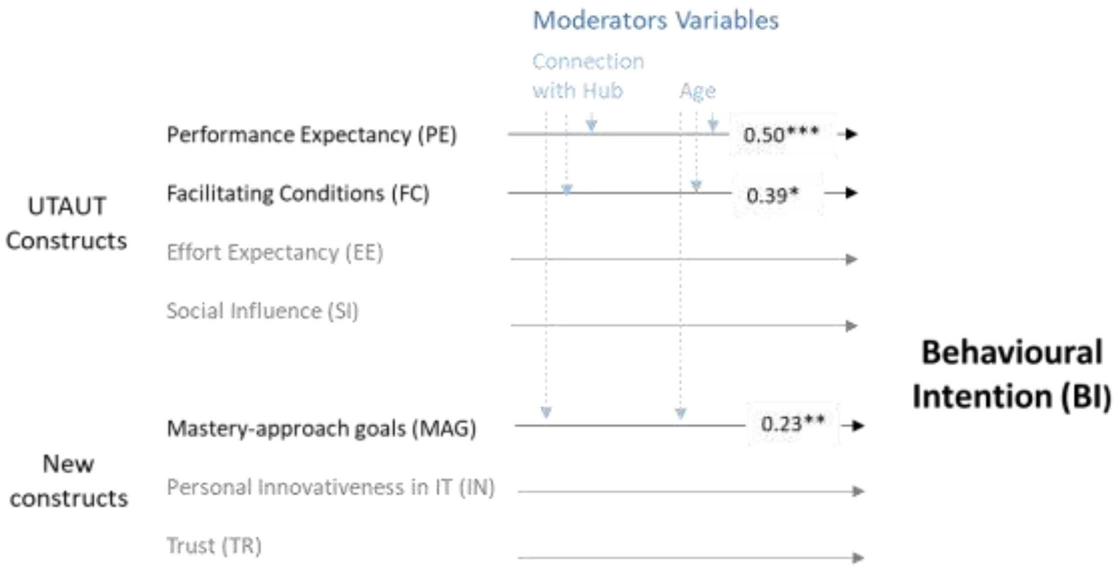


Figure 1. PE, FC and MAG affect farmers' willingness to adopt an agricultural information app. The blue items show a moderation effect of "Connection to an Innovation Hub" on PE, FC, SI and MAG. MAG was not in the original UTAUT model. Significance codes: * at $p < 0.05$, ** at $p < 0.01$, *** at 0.001.

3. Materials and Methods

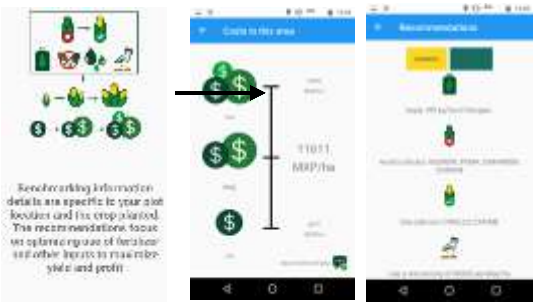
3.1. Research context

The study area is the state of Guanajuato is divided in 46 municipalities with 5.8 million inhabitants in total. Agriculture is important in the Mexican state of Guanajuato, with 31% of its area dedicated to agriculture [37] and areas such as the Bajío region became important for agriculture and livestock. Around 85% of its harvested area is sown to beans and cereal grains including sorghum, wheat, maize, and barley [38,39]. Guanajuato had the highest agricultural production in the country in 2019, with sorghum yields barely at the national level and the second highest yields for wheat (6.8 t/ha) just after Sonora state (6.9 t/ha). At nearly 12 t/ha, the state's average maize yields are among the highest in Mexico [40].

CIMMYT has been working on innovation in agri-food systems in Mexico for the past decade, funded through partnerships with several actors, of which the Government of Mexico has been the largest funder, both at the federal level through the Ministry of Agriculture and at the state level in Guanajuato. Work takes place through 12 innovation hubs located strategically throughout Mexico; the hubs seek to integrate farmers and local and regional value-chain actors for maize- and wheat-based farming systems [35]. This study is building on the work in the hub in Guanajuato. The hubs comprise research platforms, demonstration modules, and extension and impact areas. The research platforms carry out joint research with local institutes, as well as generating and sharing new knowledge and adapting farming innovations for their specific areas. The demonstration modules are on farmers' land and involve side-by-side fields managed using new technologies or conventional practices, for comparison. Module outcomes are often fed back to research platforms and allow for farmer-to-farmer interaction and sharing, with the aim to drive adoption, to have local impacts, and to scale useful innovations. Extension areas are parcels where farmers have applied learnings from demonstration modules. Impact areas finally are defined as places where farmers who are not directly connected to the hubs have adopted the program's innovations [42] (p. 69-71).

Created in 2017 and currently in a second phase of development by the International Institute of Applied Systems Analysis (IIASA-Austria), the AgroTutor mobile phone application is a pilot project of CIMMYT that is being tested in Guanajuato, Mexico. The app provides farmers with access to best practices and geo-referenced and timely information about fields and crops, including benchmarking data for crop placement, timely agronomical recommendations (i.e. optimizing use of fertilizers), potential yield and financial benchmarking information (i.e. prices and costs), historical and forecasted weather data, and other expert sources of agricultural information in the region. Farmers can also provide their own information regarding soils, management and yields, for use in crop models and for generating improved recommendations [17].

Farmers can consult targeted benchmarking information:



Farmers can geo-locate, register plots and agricultural activities

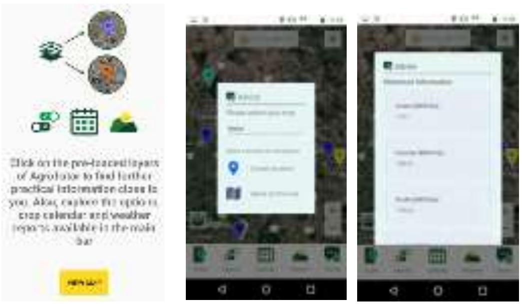


Figure 2. AgroTutor app with main activities (Extracted from App website, [17]).

3.2. Data collection, sampling and measurement tool

In 2019, we conducted a survey through face-to-face interviews with farmers in the El Bajío region of Guanajuato using the GeoODK mobile phone app, an open-source tool. A database (2014-2019) of presumably active farmers in the Innovation hub containing their correspondent municipalities was used to select the respondents and comprised two stages. First, respondents that were connected to the hub were randomly selected from the mentioned database. In some cases, we learnt that the farmer passed away or couldn't be reached after several attempts. Then, another farmer connected to the innovation hub in the same municipality was surveyed. Two municipalities were removed from the sampling frame because of security reasons, a result of increased drug cartels activity in the region. The second stage of the sampling comprise farmers not connected to the innovation hub, in the same municipalities, approached at meeting points (while they were waiting in a que) or before events in the region (association, presentation of agricultural products, etc.). Around one out of two non-connected farmers approached accepted to take the survey. Therefore, a similar number of non-connected farmers were approached and interviewed in the same municipalities. A total of 394 responses were obtained (205 from MasAgro-connected farmers and 189 from non-connected farmers), with no missing values. We obtained prior informed verbal consent from all respondents and no personal data were gathered.

Farmers were surveyed using standardized questions based on [30] and [18] with sections covering general information and demographic characteristics, their history of use of mobile phones to access agronomic data and recommendations, and questions of the model used. An introductory text made clear that the questions were related to the potential use of a mobile phone app to access agricultural data (Appendix A). All farmers viewed a short video describing the app and its salient features, prior to responding to the measurement items. Each construct was based on three-to-five items as recommended by [43]. A total of 30 measurement items adapted from prior studies were carefully rephrased

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for the context of agriculture-related mobile phone app (Appendix B) with response selections on a seven-point Likert scale ranging from "Totally disagree" (1) to "Totally agree" (7). The surveys were pilot tested with farmers, extension agents and enumerators (Appendix A – Questionnaire).

3.3. Estimation techniques and data analysis

Statistical analyses were performed using the lavaan R package [44] and SPSS. Demographic data were first analysed using descriptive statistics. Then a Structural Equation Modelling (SEM) was conducted to test the model presented in Fig. 1. A structural equation model is a set of statistical models that seek to explain the relationships between multiple variables; it was used because it allows to simultaneously analyse all relationships, combining multiple regression with factor analysis, while allowing for both observed and latent variables to be analysed together [43]. First, a confirmatory factor analysis (CFA) was conducted using Maximum Likelihood Estimation to examine reliability and validity of our measurement model. Second, we evaluated the path analysis of the structural model estimates to test the significance of our hypotheses and the predictive items of the proposed model. Prior to assessing the measurement and structural models, Common Method Variance (CMV) and multi collinearity were tested. To check for common method bias, the Harman (1976) single factor test was employed iteratively in SPSS. Result showed that all factor(s) accounted for <50% of the variance. Hence no factor was found to account for most of the variance in the variables, confirming that the common method variance is not a concern in the data. To test multicollinearity, Variance Inflation Factors (VIFs) and tolerance were computed in R for the constructs and they were found to be less than the threshold of 5 and greater than 0.1 respectively, suggesting that multicollinearity was not a major issue in our study [43].

The general fit of the measurement and structural models were assessed using a combination of absolute and relative indexes: normed chi-square (CMIN/DF), Adjusted Goodness-of-Fit Index (AGFI), Comparative Fit Index (CFI) or the Tucker Lewis index (TLI), and Root Mean Square Error of Approximation (RMSEA). For both the measurement and structural models to have sufficiently good fit, based on the sample size these measures needed to be <3, ≥0.8, ≥0.92 or 0.94, and ≤0.7 respectively [43,46]. For the structural model, the strength and significance of the relationship between each of the constructs and behavioral intention were assessed using standardized regression weights (SRW) and p-value ($p < 0.05$). Prior to the path analysis (hypotheses testing), the measurement model was also assessed for (i) construct reliability, (ii) indicator reliability, (iii) convergence validity, and (iv) discriminant validity. Construct reliability is a measure of the internal consistency of the measurement items and was assessed using composite reliability (CR) and Cronbach's alpha values [43]. The indicator reliability was evaluated based on factor loadings. Convergence validity measures whether items can effectively reflect their corresponding construct (i.e., converge on the intended construct), whereas discriminant validity measures whether two constructs are statistically and theoretically different [43]. Average variance extracted (AVE) was used as the criterion to assess convergence validity [47]. To examine discriminant validity, we used the Heterotrait-Monotrait Ratio (HTMT) computed using lavaan in R [44].

Finally, we conducted a multi-group analysis to assess the moderation effect of farmer's age between UTAUT constructs and behavioral intention (Fig. 1). For the factor 'age', respondents were divided into two groups, based on the average age in the sample. Farmers under the median age 55 years old ($n = 201$) were grouped as younger farmers and those of 55 years or older ($n = 193$) were designated as older farmers. 'Gender' as moderator variable in the UTAUT model was not further considered because very few female farmers participated in the study. As part of the analysis, measurement model invariance, which includes configural and metric invariance, was assessed following the three-step procedure presented in [48]. Configural invariance checks if the factor structure is invariant across groups, indicating that participants from the different groups understand the constructs in the same way [49]. Metric invariance tests if different groups respond to the items in the same way. That is, it checks if the strengths of the relationships between specific items and their respective underlying construct (i.e. factor loadings) are the same across groups [49]. A detailed procedure followed on how to assess configural and metric invariance can be found in Appendix C. Fit indices for the fully constrained measurement model between younger and older farmers (CMIN/DF = 2.169; CFI = 0.932; RMSEA = 0.077), and between connected and non-connected farmers (CMIN/DF = 2.367; CFI = 0.926; RMSEA = 0.083; SRMR=064) were satisfactory. The results of the partial constrained measurement models were compared to those of the unconstrained multi-group measurement models using a chi-square difference test. The chi-square difference test for the two groups was not significant, suggesting that partial metric invariance for the two groups was also met following [49]. After assessing the criteria for both configural and partial metric invariance at the measurement model level, invariance analysis at the structural model level was conducted (Appendix C).

4. Results and discussion

4.1. Descriptive statistics

The characteristics of the farmers surveyed in this study are presented in Table 1a. Most respondents were male (94%) and 69% of the respondents were between 41 and 70 years old. This age distribution is in line with a national survey by INEGI in 2017. Most respondents own a mobile phone (82%) and 37% have started using a smartphone in the past 5 years (Table 1b).

***Table 1.* a.** Demographic characteristics of the surveyed farmers.

Factor	Frequency (394)	Percentage (%)
Gender		
Male	370	93.9
Female	24	6.1
Age (years)		
16-30	17	4.3
31-40	48	12.2
41-50	74	18.8
51-60	112	28.4
60-70	86	21.8
71 or older	57	14.5
Educational level		
none	48	12.2
Primary school	140	35.5
Secondary school	130	33.0
Higher education	76	19.3
Marital status		
Single	53	13.5
Married	336	85.3
Co habitation	5	1.3

The INEGI survey reports that at a national level 33% of the production units use information and communication technology for agricultural activities. The 90% of the INEGI surveyed production units have a cell-phone/mobile phone. For Guanajuato it is reported that 50% use ICT and 90% of the production units owns a mobile phone [50]. This is comparable with the 82% observed in our sample (Table 1b).

***Table 1.* b.** Distribution of mobile phone ownership and use by surveyed farmers.

Factor	Frequency (394)	%

Own a mobile (all types)		
Yes	324	82.2
- smartphone	181	
- feature phone	66	
- basic	77	
No	70	17. 8
Years of using a smartphone		
0-5 years	147	37.3
6-10 years	30	
11-15 years	4	

4.2. Evaluation of the measurement model

The first fit of the measurement model that included all the items of the constructs was sufficient. The model fit indices resulted in a "good measurement model" [43] with the following index values: CMIN/DF: 2. 577; AGFI: 0.823; CFI: 0.941; and RMSEA: 0.063 (Table 2). The measurement model assessment of (i) construct reliability, (ii) indicator reliability, (iii) convergence validity, and (iv) discriminant validity is shown in Table 3. All the constructs showed composite reliability (CR) and Cronbach's alpha values greater than 0.7, indicating that the construct's reliability criterion was met [43]. The factor loadings for all items were greater than the threshold value of 0.7, confirming a good indicator reliability of the instrument (Table 3). No items needed to be dropped because of low factor loading. The convergence validity was tested with the Average Variance Extracted (AVE) value [47]; and all the constructs had an AVE greater than the minimum acceptable value of 0.5 confirming the convergence validity criterion was achieved.

Table 2. Summary of fit indices for the measurement and structural models.

Model fit indices	**Recommended value**	**Model results**	**Reference**
Normed chi-square (CMIN/DF)	<3	2.58	[43,46]
Comparative Fit Index (CFI)	Above 0.92 or 0.94	0.933	[43,46]
TLI (Tucker-Lewis Index)	Above 0.92 or 0.94	0.932	[43]
RNI	Above 0.90	0.941	[43]
SRMR	0.09 or less (with CFI above 0.92)	0.052	[43]
Root Mean Square Error of Approximation (RMSEA)	Value <0.08 (with CFI of 0.92)	0.063	[43,46]
Adjusted Goodness-of-Fit Index (AGFI)	>=0.8	0.823	[43]

Table 3. Summary of reliability and validity measures of the measurement model.

Construct	**Number of items**	**Composite reliability (CR)**	**Cronbach's alpha**	**AVE**	**Factor loadings**
BI	3	0.916	0.915	0.786	0.850-0.905
PE	4	0.898	0.896	0.687	0.787-0.851

EE	4	0.932	0.931	0.774	0.843-0.902
FC	4	0.836	0.825	0.570	0.621-0.835
SI	4	0.884	0.882	0.656	0.800-0.825
TR	5	0.926	0.925	0.714	0.770-0.887
MAG	3	0.913	0.913	0.777	0.867-0.895
IN	3	0.846	0.842	0.646	0.685-.883

Discriminant validity can be derived from table 4, where the matrix shows the HTMT values between each pair of factors, which appear to be all below 0.9. The overall results indicated that the model had good indicator and construct reliability and convergence and discriminant validity, confirming that the constructs were statistically distinct and could be used to test the path analysis of the structural model.

Table 4. A matrix showing HTMT values between each pair of factors.

	BI	**PE**	**EE**	**FC**	**SI**	**TR**	**MAG**	**IN**
BI	1							
PE	0.845	1						
EE	0.629	0.547	1					
FC	0.792	0.651	0.878	1				
SI	0.709	0.695	0.551	0.728	1			
TR	0.483	0.457	0.386	0.484	0.617	1		
MAG	0.795	0.687	0.536	0.770	0.794	0.532	1	
IN	0.741	0.681	0.561	0.707	0.786	0.602	0.795	1

4.3. Path Analysis estimation and results

After assessing the measurement model, the structural model (path analysis) was assessed. The overall model fit for the structural model was good (Table 2). Values of the indices CMIN/DF, CFI, TLI, RNI, SRMR, RMSEA and AGFI were almost the same as the measurement model. The path analysis showed that three hypotheses were supported (Table 5). Significant positive impacts on behavioral intention (BI) were found for performance expectancy (PE) (confirming H1), facilitating conditions (FC) (confirming H3) and mastery approach goals (MAG) (confirming H6). The two factors from the UTAUT model explained 25%, while adding the construct of mastery-approach goal increased this to 39.5% of the variance in farmers' intention to adopt the app. Among the tested constructs (apart from the UTAUT) the mastery–approach goals (H6) had a significant impact on the intention to adopt the mobile phone app indicating that farmers believe that mastering the use of an app might help them to improve their level of competence and knowledge on agriculture [51].

Table 5. Summary of results of path analysis of the structural model.

Hypothesis	**Structural Path**	**Estimates**		**Result**
		SRW	p-Value	
H1	PE → BI	0.500	**0.00*****	Supported
H2	FC → BI	0.394	**0.014***	Supported
H3	EE → BI	-0.123	0.315	Not supported
H4	SI → BI	-0.076	0.277	Not supported
H5	MAG → BI	0.228	**0.007****	Supported
H6	IN → BI	0.065	0.358	Not supported
H7	TR → BI	0.025	0.544	Not supported

Significance codes: * at $p < 0.05$, ** at $p < 0.01$, *** at 0. Note: SRW=Standardized Regression Weight.

BI=Behavioral intention, PE=Performance expectancy, EE=Effort expectancy, SI=Social influence, FC=Facilitating conditions, TR=Trust, MAG=Mastery approach goals, IN=Innovativeness.

The finding of the relationship between performance expectancy with behavioral intention (H1) is consistent with earlier studies on mobile banking (Baptista and Oliveira 2015; Oliveira et al., 2014). For agriculture, studies also found the importance of performance expectancy on the intention of farmers to adopt decision support tools (Rose et al., 2016), mobile based communication technologies for agricultural information [52] and SMS agricultural advice [30]. This implies that farmers' intentions to use apps will be strengthened if they believe that the apps offer greater performance in their daily agricultural activities. Moreover, 66% of the surveyed farmers selected from a list of potential benefits of an app the "faster way of getting information."

No significant relationships were observed between behavioral intention and the other constructs implying that hypotheses (H2, H4, H5, H7) could not be supported and were not found to predict the behavioral intention to use an app significantly. The lack of effect of effort expectancy implies that farmers might not find the effort required to use the mobile phone app important in their intention to adopt. This can be partially explained by the ubiquitous presence of cell phones with 46% of the sample owning a smartphone, see Table 1b). Hence the ease-of-use seems of low importance for farmers already familiar with apps for instant messaging. As 'connected farmers' in the current study are participants of the same program it was anticipated that social influence would positively affect behavioral intention to adopt the app, but this was not the case nor was it the case in a previous study on SMS use [30]. This implies that farmers will not simply adopt a technology because important others (e.g. friends or neighbours) are using it. Similarly, an effect of personal innovativeness was expected as the farmers willing to participate in the hub are innovative or cooperative leaders who have joined the program voluntarily [42] (p. 70). However, within this group no effect of personal innovativeness (H7) on the intention to adopt was revealed. In general, this implies that in this context the willingness of an individual to try out new technologies does not affect the adoption of the mobile phone app.

Unlike in previous studies on SMS services [30] and Decision Support Tools [7] already being launched and used by farmers, trust in this study was not found as significant factor. The low influence of trust on the intention might be partially explained because, contrary to those studies, the provision channel (e.g. extension agent) promoting the use of the app is not yet implemented fully in the region. This might change when the last version of the mobile phone app is launched and the provision channel begins to promote it with the specific features, recommendations and data sharing characteristics.

4.4. Multi-group analyses

The assumption of full metric variance was tested but could not be met. Modification indices were calculated to test for any linear constraints that could be relaxed to improve the model fit whilst accounting for changes in all the parameters. By leaving two item loadings unconstrained for a non-significant path (SI), acceptable model fits were obtained for the partial metric invariance models (all ΔCFI < 0.01). Partial metric invariance is the minimum criterion required [53]. This indicated that the latent variables had the same meaning across groups and that SEM analysis could be performed on the pooled sample. Only when configural and partial metric invariance at the measurement model level were established, multi-group analyses were conducted at the structural level. Because no hypotheses were available for the added constructs (IN, TR), the included variables were limited to the ones from UTAUT plus mastery-approach goals (MAG).

Results of the moderator effect of age revealed that performance expectancy is more important for older farmers (Table 6) as it shows a significantly higher effect of performance expectancy on behavioral intention. Similarly, the effect of facilitating conditions was significant only for older farmers. On the contrary, the effect of mastery-approach goals on behavioral intention was significant for younger farmers but not for older farmers. As for the multigroup analysis, performance expectancy was more important for non-

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connected farmers (Table 7). The influence of MAG on the intention of younger and non-connected farmers to adopt sheds light on the type of utilitarian benefit to reach those farmers who are not connected to the hub yet (Table 6). Utility refers to the usefulness or value that consumers experience from a product or service. Examples of utilitarian benefit might be special access to trainings and capacity building in their regions. The MAG seems to have an effect only on non-connected farmers, while facilitating conditions seems to have an effect only for connected farmers (Table 7). Therefore, the different groups might need different stimuli for an initial adoption once the app is rolled-out. Finally, for new and non-connected participants' engagement, focusing on performance expectancy might be a suitable strategy for initially adopt the app. Results showed that the effect of performance expectancy on behavioral intention was significantly higher for non-connected farmers (Table 7). The standardized regression weights (SRW) revealed that the mastery approach goal was significant only for non-connected farmers.

Table 6. Multi-group analysis between younger and older farmers.

Hypothesis	Structural Path	Younger farmers		Older farmers	
		SRW	p-Value	SRW	p-Value
H1	PE → BI	0.469	***	0.690	***
H2	FC → BI	0.199	0.338	0.946	**0.019***
H3	EE → BI	0.018	0.905	-0.358	0.119
H4	SI → BI	0.019	0.884	-0.078	0.566
H5	MAG → BI	0.431	**0.002****	0.125	0.457

Significance codes: * at p < 0.05, ** at p < 0.01, *** at 0. Note: SRW=Standardized Regression Weight. BI=Behavioral intention, PE=Performance expectancy, EE=Effort expectancy, SI=Social influence, FC=Facilitating conditions, MAG=Mastery approach goals.

Table 7. Multiple-group analysis between non-connected farmers and connected farmers.

Hypothesis	Structural path	Non-connected farmers		connected farmers	
		SRW	p-Value	SRW	p-Value
H1	PE → BI	0.716	***	0.485	***
H2	FC → BI	0.418	0.221	0.622	**0.027***
H3	EE → BI	-0.171	0.393	-0.087	0.61
H4	SI → BI	-0.258	0.079	0.079	0.462
H6	MAG → BI	0.485	**0.004****	0.195	0.126

Significance codes: * at p < 0.05, ** at p < 0.01, *** at 0. Note: SRW=Standardized Regression Weight.

BI=Behavioral intention, PE=Performance expectancy, EE=Effort expectancy, SI=Social influence, FC=Facilitating conditions, MAG=Mastery approach goals.

5. Implications and limitations

5.1. For the designers, developers and project managers

Design-thinking principles have been applied and adapted by CIMMIYT when creating innovation hubs [54]. The prototyping phase is crucial to gain early insights before a solution is launched, "the sooner you put it in front of participants to react to, the faster you'll get to a value-added solution." In this study, it was proven that using the UTAUT framework, and conducting a SEM analysis are suitable to learn more about the farmers' initial adoption decision. Amongst the factors revealed, performance expectancy is the

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strongest predictor of farmers' intention to adopt and the proposed agricultural information app. This signals that in order to promote this kind of mobile phone apps for decision support in the agricultural domain, focusing on the performance expectancy through different approaches such as user engagement is worth exploring further. Development of a digital decision support tool requires early and ongoing interactions with targeted users to map app performance, objectives and preferences, ensure reliability of scientific input, and optimize the user experience [9]. The [55] study listed challenges and proposed solutions for ICT-based agriculture implementations such as provision of offline features, timely and relevant advice and integration of different appropriate delivery channels (e.g. SMS, Interactive voice Response – IVR). The rapid changes in these technologies also change the way that decision support systems are being designed and will be used. Therefore, researchers need to adapt and extend current adoption models such as the UTAUT further integrating socio-psychological approaches. For future phases, the continuous application of farmer-centered design connecting with their needs might tackle observed low user adoption and can increase the chances of launching a successful decision support service.

Moreover, similar to the "facilitating conditions" construct, previous studies had highlighted the importance of interoperability and compatibility with existing infrastructures. In other words, considering the existing information ecosystem of farmers. In this respect, the mobile phone app can be integrated, for example, with previous efforts such as the SMS service MasAgro Móvil. MasAgro Móvil uses the Extensio platform (previously Esoko), to send text messages to the hub network with information about prices, weather and general advices on conservation agriculture practices [37]. Other existing information channels that could be integrated are through the fertilizer distributors, social media or Instant messaging apps and groups. Consideration of the existing, mostly informal settings, and further building on that can increase the possibilities for the adoption of solutions [56].

Given that performance expectancy and facilitating conditions significantly predicted farmers' behavioral intention to adopt the studied app, project managers might ensure that the app offers utilitarian benefits to the farmers such as actual payment in phone credit [5] and that the technical infrastructure exists to help them to use it. Examples of this are the offline features being developed by AgroTutor' developers to cope with unreliable internet connection in rural areas and the potential support of extension agents in early stages of usage. Moreover, the difference in the importance of mastery-approach goals (MAG) between farmers connected and not connected to the hub indicates a heterogeneity level of farmers profiles even in the same region. Hence, different utilitarian benefits need to be designed to promote adoption in each group. Another enabling environment element is mutual trust, it is considered a best practice despite not being observed in the present work. This is already the case for the innovation hubs, but special attention needs to be taken when bringing new stakeholders to the initiative. Not only working with local institutes that have been already accepted but also stimulating them to co-design the app could be a way to establish initial trust between farmers and the initiative. For example, the co-creation of value has been proved insightful to understand bottom-of-the-pyramid market dynamics in countries like Bangladesh [57].

5.1. Limitations

Despite its contributions regarding aspects that are important for farmers to adopt a mobile phone app to provide agricultural-related information about crops, some limitations merit discussion. First, the factors important for technology adoption might differ from location to location, so assessing the validity of this model with farmers across different cultures both in developed and developing countries would be theoretically and practically useful. By the same token, our findings are specific for a certain part of Mexico and the context can be very different in other areas (e.g., areas with lower literacy and less smart-phone adoption). Therefore, care must be taken before generalizing to other geographies with other ICT infrastructures. Moreover, the study does not claim to statistically represent farmers in Mexico (nor in terms of gender and, nor geographically). It would be interesting to test the model with more female farmers and in other parts of Mexico. Secondly, since most of the farmers in this study had not used the mobile phone app, we did not examine the effect of behavioral intention on the use behavior. Therefore, it is recommended that future research includes the examination of the effect of behavioral intention on farmers' actual use behavior. Additional research would also allow assessing if the importance of the constructs would change over time or contexts. For example, the effect of trust on farmers' behavioral intention to use the mobile phone app might become important when the information is being shared with particular organizations, including companies, along with the perceived risk associated with use [29,58]. Then data sharing perceptions are possibly a crucial issue that warrants further study.

6. Conclusions

Agricultural mobile phone applications can provide tailor-made agronomic advice to small-scale farmers, who are often - excluded from precision agriculture developments, while at the same time contributing to Citizen Science applications promoting sustainable agricultural intensification. Nevertheless, research on initial adoption decision of agricultural apps in the region of Central and Latin-America is limited. In this study we extended the commonly used UTAUT framework to reveal the main behavioural aspects of Mexican farmers' intention to adopt agricultural apps including understudied farmers' intrinsic motivations. Performance expectancy was found to be the strongest predictor of farmers' intention to adopt an app to provide agricultural information. This clearly highlights the importance of understanding the benefits perceived by farmers. Thus, managers of agricultural projects aiming to deploy mobile phone apps need to ensure that their use for data collection offers benefits to farmers, such as mobile credit compensations.

Mastery-approach goals (MAG) were found significant, it revealed a baseline of farmers' intrinsic motivation ('why' are they motivated to use it in the first place) independently of the content of the application. This is of special interest for the initial decision to adopt, their readiness to learn and master the use of an app providing agricultural innovation. As well, these results motivate to explore further how non-financial incentives such as access to training during the rolling out of the app might promote its uptake. In addition, younger farmers with a mastery goal orientation can also be targeted in early stages of the app roll-out as they are expected to use the mobile phone app to acquire new skills and knowledge. Then the mobile phone app needs to be accompanied by facilitating conditions and so-called basic conditions such as access to a smartphone and reliable internet access. It was revealed that performance expectancy was important for farmers connected and non-connected to the innovation hubs and for both older and younger farmers. According to the results of the study the 'connectedness to an innovation hub' in the region has a moderator effect on the intention to adopt. Then, further research should focus on ways to complementary assess the farmers' perception of the enabling innovation environment relevant for research-for-development efforts. For example, research in the areas of the so-called Agricultural Innovation System can be a way forward. Finally, the study should be validated and extended to other geographical areas in Mexico and Latin America since the magnitude of factors may differ and important to consider for user engagement of farmers in these regions.

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Appendix A

Questionnaire to assess a mobile phone app technology acceptance of famers in Guanajuato
The main purpose of this survey is to assess a mobile app technology acceptance of farmers as a data provision tool to provide agricultural information and their preferences around the use.

1. Background information (filled by enumerator)
Date: Municipality: Village:

2. Introduction
[Introduce yourself] Thanks a lot for the time you are taking today. This survey has the objective to evaluate the factors that affect the potential willingness to use and the stated preferences when using a mobile phone app for agricultural purposes. The results will be used only for research purposes and I assure your confidentiality. This survey will be divided into 3 parts. I will need to register the data on my cell phone, I hope it does not bother you. In the first part I will ask you some general questions, in the 2nd part I will give you some options to choose from. The third part contains questions about your intention to use (or not) an application. Thanks again for your time. Do you have any question so far?
3. General information of the respondent
How old are you?: _____years Gender: [ ] Male [ ] Female
Marital status? [ ] Married [ ] Single [ ] Co habitation [ ] Other
Do you have any children (sons or daughters) from the age of 18-35? [ ] Yes [ ] No
What is your educational level?
[ ] None [ ] Primary school [ ]Secondary school [ ] Higher education [ ] Other, specify_______
Can you read and write? [ ] Yes [ ] No
4. Farming system (s)
What are your main sources of livelihood and income?
[ ] Farming (grain) [ ] Livestock [ ] Horticulture [ ] Other off-farm income
What is the total land size of your sowed plot (s)? (ha) ______ha
How many crops do you usually sow (average situation)? _______ P/V: O/I:
Do you have any agricultural contract nowadays? [ ] Yes [ ] No
Are you the owner of the farm or plots?[ ]Yes [ ]No Around how many hectares you own? __ha
5. Extensionist services
Are you a member of the Innovation Hub (MasAgro)? [ ] Yes [ ] No
For how many years have you been in contacted with the Innovation Hub?___ years
Do you receive any additional extensionism service? [ ] Yes [ ] No
How frequent did you receive advices from extensions' agents?

[ ] Never [ ] every 3 days [ ] Weekly [ ] Monthly [ ] Bi-monthly [ ] Once every 6 months

Which are your main sources of information to get agricultural (agronomic) information and advices?

[ ] Extension agents
[ ] Organisations
[ ] Direct communications with neighbours
[ ] Meetings & Events
[ ] TV/Radio/Newspaper
[ ] Social media
[ ] Mobile phone based (SMS, Whatsapp groups, Ag apps)
[ ] Internet (websites)

Do you normally follow what the previous sources advise you? [ ] Yes [ ] No

If No, Which will be the reasons for not following the advices provided by your main sources?

[ ] Not specific to my location
[ ] Inappropriate availability of quality inputs (seed, pesticides and fertilizers)
[ ] Poor or no access to soil and/or water testing
[ ] Poor access to markets
[ ] Financial constraints
[ ] Others issues______________

From the following list of information on agriculture, what information do you find most useful? (max 3)

] Weather
[] Input use in general (fertilizers, seeds, ago-chemicals)
[] Yields prediction
[] Income and costs from nearby farms
[] Advise to manage pest, diseases and weeds
[] Prices forecasting

Network and Mobile phone info.

Which is the approximate distance to nearest good mobile network place (walking distance in minutes)?

[ ] 0min (on my own farm/home)
[ ] 5-15 min.
[ ] 30 min.-60 min
[ ] more than 1 hour

Mobile phone ownership: [ ] Yes [ ] No

On average, how much did you spend per month in mobile (Mexican pesos/month)? ________

Which kind of phone? [ ] Smart phone [ ] Mid-range Phone [ ] Basic Phone

For how long, have you own a smart phone?

On a day, around how much time do you spend on your smart phone on average? ____minutes

What are the main benefits you perceive about obtaining agricultural information on cell phones?

[ ] None
[ ] It is a fast way of getting information
[ ] Better connected to markets
[ ] Better prices
[ ] Increasing yields
[ ] Other

9. Familiarity with existing agricultural extension apps.

Do you know any existing apps for agricultural purpose in the region? [ ] Yes [ ] No

If you remember the name, could you please provide it? ____________

Will you be willing to use them? Yes [ ] No [ ]

If no, why you would not use it?
[ ] I do not have a phone
[ ] I do not have financial means to top up my mobile phone
[ ] I do not know how to use it
[ ] I am not interested
[ ] Other

10. Scripted intro.

First, I would like to thank you once again for participating in this interview. The questions I ask you after this point are related to the mobile phone or smartphone, mainly the use of your mobile phone to consult and receive agronomic information. Thank you for your valuable time and we will proceed to the questions. Please indicate the degree to which you agree with each statement by using the scale 1 (Disagree strongly), (4) being neutral, to 7 (Agree strongly). See Appendix 3.C Measurement Constructs

12. Thanks and ask if anything is wanted to be add

Appendix B

Constructs	Items	ID	Source
Behavioral Intention (BI)	-In the future, I intend to use or continue using mobile phone apps that provide me with any agronomic information. -I will always try to use mobile phone apps that provide me agronomic information, in my daily life. -I plan to use or continue using mobile phone apps frequently that provide agronomic information.	BI1 BI2 BI3	[18,20,30]
Performance expectancy (PE)	-I find agronomic advices provided through a mobile phone (cellphone), useful in my daily life. -Use a mobile phone (cellphone) app helps me to increase my productivity. -Using a mobile phone (cellphone) app on a mobile phone (cellphone) helps me to me to accomplish things faster on my plots. -Using a mobile phone (cellphone) increases my possibilities of achieving higher crop yields.	PE1 PE2 PE3 PE4	[18,20,30]
Effort expectancy (EE)	-Learning how to use a mobile phone (cellphone)' app is easy for me. -My interaction with a mobile phone (cellphone)' app is clear and comprehensive. -I find the mobile phone (cellphone)' apps easy to use. -It is easy for me to become skilful at using mobile phone (cellphone)' apps	EE1 EE2 EE3 EE4	[18,20,30]
Social influence (SI)	-People whose opinions I value, prefer that I use mobile phone (cellphone) apps-People who influences how I behave think I should use mobile phone (cellphone) apps -People who are important to me think that I should use mobile phone (cellphone) apps -People who are important to me would use mobile phone (cellphone) apps themselves.	SI1 SI2 SI3 SI4	[18,20,30]
Facilitating conditions (FC)	-I have the necessary resources to use a mobile phone (cellphone) app.	FC1	[18,20,30]

	-I have the necessary knowledge to use a mobile phone (cellphone) app. -The mobile phone (cellphone) apps are compatible with other technologies I use -I can get help from others when I have difficulties using a mobile phone (cellphone)	FC2 FC3 FC4	
Trust (TR) *Trust in extension (app provider) vs. project*	- The extension services provider is very concerned about my crop (s) production. -My needs and desires are very important to the extension services provider - The extension services provider would not knowingly do anything to hurt me - The extension services provider really looks out for what is important to me - The extension services provider will go out of its way to help me	TR1 TR2 TR3 TR4 TR5	[30,31]
Mastery-approach goals (MAG) *MAG in the actual app vs. app' advices*	-I want to learn as much as possible about an agricultural mobile phone (cell phone) app. -It is important for me to completely understand the recommendations provided by the agricultural mobile phone (cell phone) app. -I desire to completely master the use of the agricultural mobile phone (cell phone) app.	MAG1 MAG2 MAG3	[30,59]
Innovativeness (IN)	-If I heard about a new technology, I would look for ways to experiment with it. -Among my peers, I am usually the first to explore new gadgets & technologies. -I like to experiment with new technologies.	IN1 IN2 IN3	[30,60]

Appendix C

To assess configural invariance, unconstrained multi-group measurement models, which allow factor loadings to vary across two groups (i.e. between MasAgro-connected farmers and non-connected farmers and between younger and older farmers) were developed. The model fit for the configural invariance between younger and older farmers was satisfactory (CMIN/DF = 2.198; CFI = 0.933; RMSEA = 0.078), and that between connected and non-connected farmers was also satisfactory (CMIN/DF = 2.403; CFI = 0.927; RMSEA = 0.062) [49]. This implied that the models fit both groups well and configural invariance was met.

To assess metric invariance, fully constrained measurement models that constrain the measurement weights (i.e., factor loadings) for each measured variable to be equal for the two groups (i.e. between younger and older farmers and between connected and non-connected farmers) were developed but could not be met. Modification indices were estimates to explore for any linear constraints that could be relaxed to improve the model fits, whilst accounting for changes in all the parameters. By leaving 2 item loadings unconstrained for a non-significant path (SI), acceptable model fits were obtained for the partial metric invariance models (all ΔCFI < 0.01). Partial metric invariance is the minimum criterion required to validate the analysis [53]. This indicated that the latent variables had the same meaning across groups and that SEM analysis could be performed on the sample.

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