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RESEARCH ARTICLE

“Anytime, anyplace, anywhere” – A sample selection model of mobile internet adoption in german agriculture

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Abstract

Mobile internet is considered one of the most important developments in information and communication technology due to its considerable effect on both the economy and our daily lives. Furthermore, mobile internet is an essential tool for overcoming the rural–urban digital divide. With respect to agriculture, mobile internet can play a central role in information gathering as well as the implementation of precision and smart farming technologies. Yet, no study has identified the determinants of mobile internet adoption in agriculture. Using a bivariate probit model with a sample selection and a representative data set from 815 German farmers, this study showed that, among other characteristics, the age of the farmer, farm size and location, as well as familiarity with internet risks is associated with mobile internet adoption in agriculture. These results may be of interest to policy makers, who deal with internet infrastructure, and providers of farm equipment that rely on mobile internet connection. [EconLit citations: Q16].

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1 | INTRODUCTION

Mobile internet is defined as wireless access to the internet via a mobile device (Chae & Kim, 2003). During the last decade, the adoption of mobile internet has increased significantly due to the fact that mobile internet, in contrast with fixed broadband, offers internet access anywhere and anytime (Gerpott & Thomas, 2014). Moreover, mobile internet has become the most dynamic platform for entrepreneurs to benefit from information and communication technologies (ICT; Alderete, 2017; Tiawat, 2013). Since the development and recent introduction of 4G technology, mobile internet provides faster speed (Kongaut & Bohlin, 2016). It is expected that mobile data traffic will rise globally from 7,201 petabytes in 2016 up to 48,270 petabytes in 2021 (Cisco, 2017). Therefore, it is not surprising that mobile internet subscriptions have already surpassed the number of fixed broadband internet subscriptions (ITU, 2017). In Western Europe, mobile internet traffic amounted to 736 petabytes per month in 2016. In 2021 it is expected to reach 4,189 petabytes per month and hence, will have almost quintupled in 5 years (Statista, 2017b). All European countries have experienced significant growth in mobile internet access rates in recent years. In 2016, 59% of citizens in the European Union (EU, 28 countries) accessed the internet via mobile devices (EuroStat, 2017) and 69% of German citizens accessed the internet via mobile devices. The share of mobile internet users is expected to rise to a penetration rate of 80% in 2022 (Statista, 2017a).

The McKinsey Global Institute (2013) described the development of mobile internet as one of 12 disruptive technologies with a very high potential economic impact. Several studies have already provided evidence that mobile internet has a positive impact on economic growth. For instance, Thompson and Garbacz (2011) found a positive effect of mobile internet on gross domestic product. Similarly, Bertschek and Niebel (2016) showed a positive relationship between mobile internet use and the labor productivity of firms. Moreover, mobile broadband is an effective tool to reduce the rural–urban digital divide, as it can fill in the gaps of fixed broadband coverage in rural areas (Prieger, 2013). High speed packet access (HSPA) coverage in rural areas households of the EU reaches a share of above 90%. Sixty-two percent of rural households in Germany have HSPA coverage. Furthermore, households in rural areas of the EU have on average 80% long term evolution (LTE) coverage. In rural areas in Germany, LTE coverage reaches a share of 88% of the households (European Commission, 2017, p. 95–96).

The internet is of great importance for the development of rural areas in general (Salemink, Strijker, & Bosworth, 2017). Since rural areas are economically characterized by agriculture to a large extent (Jeffcoat, Davis, & Hu, 2012; Morris, Henley, & Dowell, 2017), the internet is also important for farmers (Kaloxylou et al., 2013; Tzounis, Katsoulas, Barzanas, & Kittas, 2017). More concretely, internet access may lead to direct production gains or benefits from cost reduction due to better links to suppliers and customers. Furthermore, better access is provided to remote sensing, public information, financial services, and geographic information system data (Aker, Ghosh & Burrell, 2016; Rolfe, Gregor, & Menzies, 2003) and can also be easily accessed via mobile internet (Hoffmann, Grethler, & Doluschitz, 2013; Tzounis et al., 2017). In addition, Thyssen (2000) forecasted that farmers will rely heavily on high-bandwidth wireless internet connections to use ICT for the support and improvement of sustainability in the production process. In keeping with this forecast, mobile internet today is one of the key technologies enabling the proliferation of precision and smart farming technologies for sustainable agriculture (Khanna & Kaur, 2019; Sundmaeker, Verdouw, Wolfert, & Pérez Freire, 2016; Xin & Zazueta, 2016). With these technologies, farmers can reduce the ecological footprint from their farming activities. For instance, leaching of fertilizers and pesticides as well as greenhouse gas emissions can be minimized using precision and smart farming technologies (Tamirat, Pedersen & Lind, 2018). Additionally, smart farming is profitable for the farmer (Walter, Finger, Huber, & Buchmann, 2017). To the best of our knowledge, literature on mobile internet adoption in agriculture is scarce. Li, Fu, and Li (2007) analyzed the attitude of farmers towards mobile commerce using the technology acceptance model framework. However, they did not focus on the actual adoption behavior rather only on the attitude towards mobile commerce which is nevertheless a well-established predictor of the actual adoption behavior.

Against this background, the objective of this paper is to analyze German farmers' mobile internet adoption. In particular, the study examines key factors of the mobile internet adoption decision. A bivariate probit model with a

sample selection using a representative data set of 815 German farmers to identify key factors affecting the adoption of mobile internet in agriculture was applied. The set of factors was hypothesized to influence mobile adoption which included farmers' and mobile internet characteristics as well as farm characteristics. Identifying factors influencing the adoption of mobile internet provided knowledge, which could be useful for policy makers as well as for businesses that can use this information for marketing strategies for farm equipment that rely on mobile internet and devices (e.g. precision and smart farming technologies).

The rest of the paper is structured as follows. Section 2 discusses several research hypotheses on the basis of a broad literature review. Section 3 presents the data collection and applied econometric model. Section 4 displays and discusses the results. The paper is then brought to a close with some concluding remarks.

2 | RESEARCH HYPOTHESES FOR MOBILE INTERNET ADOPTION

The widespread diffusion of innovation theory by Rogers (2003) has been applied in several scientific disciplines to explain technology adoption by individuals, social groups or organizations¹. This theory considered several variables which were expected to influence the technology adoption. The set of variables included adopter and innovation characteristics as well as firm characteristics. Based on that, the hypotheses in this study dealt with farmers, mobile internet, and farm characteristics. To the best of our knowledge, literature on mobile internet adoption in agriculture is scarce. Therefore the hypotheses also derived from information technology and mobile internet adoption literature in general. The study also referred to literature concerning computer and internet adoption by farmers. Table 1 provides an overview over the derived hypotheses.

2.1 | Farmers' characteristics

Smith, Goe, Kenney, and Paul (2004) analyzed internet adoption on U.S. farms and concluded that internet and computer adoption declines with each year of advancing age. Indeed, internet access is higher among younger adults in general as shown by descriptive statistics in Poushter (2016). Koch and Frees (2016) showed that a higher share of young adults use mobile internet. Therefore, it is also not surprising that with respect to mobile internet adoption and use, several studies showed that adoption declines with advancing age (Ertiö & Räsänen, 2017; Gerpott, Thomas, & Weichert, 2013b; Jiang, 2008). Therefore the following was hypothesized:

H1: *Older farmers are less likely to adopt mobile internet.*

With respect to information technology adoption decisions, gender plays an important role (Venkatesh, Morris, & Ackerman, 2000). In agriculture, female farmers tend to be less likely to adopt new technology than male farmers (Doss & Morris, 2000). However, regarding internet adoption in agriculture, results are mixed. For instance, Adamides, Stylianou, Kosmas, and Apostolopoulos (2013) found no correlation between gender and internet adoption, whereas Ernst and Tucker (2001) found gender to be associated with internet adoption. In specific, they found that male farmers are more likely to be internet adopter. Koch and Frees (2016) as well as van Eimeren and Frees (2011) showed that a higher share of men access the internet using a mobile device. For the adoption of mobile internet, Jiang (2008) found that adopters were more likely to be male. Therefore the following was hypothesized:

H1b: *Male farmers are more likely to adopt mobile internet.*

¹For an overview see Dedehayir, Dedehayir, Ortt, Riverola, and Miralles (2017).

TABLE 1 Overview of the proposed hypotheses

Variable	Hypothesis	Expected effect
H1a Age	Older farmers are less likely to adopt mobile internet.	-
H1b Gender	Male farmers are more likely to adopt mobile internet.	+
H1c Education	More highly educated farmers are more likely to adopt mobile internet.	+
H1d Innovativeness	More innovative farmers are more likely to adopt mobile internet.	+
H2 Familiarity with internet risks	Farmers, who believe to be well-informed about the dangers of the internet, are less likely to adopt mobile internet.	-
H3a Farm size	Farmers from larger farms are more likely to adopt mobile internet.	+
H3b Region	Location of the farm in the southern region of Germany is negatively correlated with mobile internet adoption.	-
H3c Berry index	Diversification of the farm is positively associated with mobile internet adoption.	+

Source: Authors' own illustration.

Education improves an individual's ability to understand and decode information (Nelson & Phelps, 1966) and is therefore one of the most important socioeconomic factors in information technology adoption (Riggins & Dewan, 2005). In line with this insight, Mishra and Park (2005) showed that more formal education is positively correlated with internet use in agriculture. In general, more educated adults access the internet (Poushter, 2016). Furthermore, education is also positively correlated with mobile internet adoption (Ertiö & Räsänen, 2017). Gerpott and Thomas (2014) identified education as an important factor influencing mobile internet use based on a literature review. Therefore, the following was hypothesized:

H1c: *More highly educated farmers are more likely to adopt mobile internet.*

Innovativeness, defined as the willingness to test new technologies (Agarwal & Prasad, 1998; Godoe & Johansen, 2012), is a central factor affecting new technology adoption (Hirschman, 1980). In the field of agriculture, Aubert, Schroeder, and Grimaudo (2012) showed that innovativeness is positively correlated with precision agriculture adoption. For mobile internet, Kim and Jee (2006) provided evidence that innovativeness is associated with the adoption of mobile internet. Hence, the following was hypothesized:

H1d: *More innovative farmers are more likely to adopt mobile internet.*

2.2 | Mobile internet characteristics

Briggeman and Whitacre (2010) provided evidence that some farmers do not use the internet due to security concerns. Moreover, Sin Tan, Choy Chong, Lin, and Cyril Eze (2009) showed that in general, security concerns are a major barrier to internet adoption. Lu, Liu, Yu, and Wang (2008) identified security and privacy risks as major concerns when using mobile data services. For instance, viruses can be transmitted through the internet and hackers may intercept signals therefore endangering the security of transmitted personal information. Therefore the following hypothesis was derived:

H2: *Farmers, who believe to be well-informed about the dangers of the internet, are less likely to adopt mobile internet.*

2.3 | Farm characteristics

Many studies have shown that farm size is positively correlated with internet adoption and usage because of their higher demand for information and organizational complexity (e.g. Mishra & Park, 2005; Mishra & Williams, 2006; Mishra, Williams, & Detre, 2009). In general, firm size is expected to influence the adoption of information technologies (e.g. Lippert & Govindarajulu, 2006; Oliveira, Thomas, & Espadanal, 2014). Balocco, Mogre, and Toletti (2009) also argued that mobile internet is more likely to be adopted by larger firms. Hence, the study hypothesized:

H3a: *Farmers from larger farms are more likely to adopt mobile internet.*

Territorial based barriers for accessing the internet are often the result of the geography of digital telecommunications infrastructure and a lack of digital connectivity (Philip, Cottrill, Farrington, Williams, & Ashmore, 2017). With respect to agriculture and internet adoption, Adamides et al. (2013), Mishra et al. (2009) as well as Mishra and Park (2005) provided evidence that the regional location of farms is correlated with internet adoption in Greece and in the U.S., respectively. Regarding mobile internet, Srinuan, Srinuan, and Bohlin (2012) showed that mobile internet adoption is affected by place of residence due to fragmentary digital infrastructure. According to the data provided by TÜV Rheinland (2017), Table A1, mobile internet coverage seems to be relatively less developed in the southern region of Germany. Taking all of this into account, the following was hypothesized:

H3b: *Location of the farm in the southern region of Germany is negatively correlated with mobile internet adoption.*

Literature on the effect of farm diversification on computer and internet adoption in agriculture reveals mixed results. Amponsah (1995) described no correlation of diversification with computer adoption, whereas Briggeman and Whitacre (2010) found a negative correlation of farm diversification and internet adoption. In contrast to that, Mishra and Park (2005) found that farm diversification is positively associated with computer adoption and suggested that owners of relatively more diversified farms have to gather more information to make farming decisions and therefore are more likely to adopt internet. According to Hitt (1999), more diversified firms have a higher demand for information technology. Despite the mixed results in the literature, the following was hypothesized:

H3c: *Diversification of the farm is positively associated with mobile internet adoption.*

3 | MATERIALS AND METHODS

3.1 | Econometric model

In this study, the dependent variables can be categorized in two parts. The first part is the adoption of a mobile device (selection stage), which is a binary outcome that determines the probability of whether a farmer adopts an internet-enabled mobile device or not ($y_1 = 1$ if yes; otherwise $y_1 = 0$). The second part (outcome stage) is a binary outcome and determines the probability of whether a farmer adopts mobile internet ($y_2 = 1$ if yes; otherwise $y_2 = 0$). The probit model is a common econometric approach which includes a dependent variable with a binary outcome by maximum likelihood estimation (Verbeek, 2008). However, estimating two probit models for the adoption of mobile devices and mobile internet would ignore the obvious correlation between the two. A bivariate probit model as an extension of the probit model takes this correlation into account (Greene, 2008). Nonetheless, the bivariate probit model does not completely account for the expected correlation between the mobile device adoption and mobile internet adoption. More concretely, adoption of a mobile device fully determines the possibility of mobile internet adoption. Hence, the outcome of the second part can only be observed if, and only if, the farmer adopts a

mobile device. Thus, a sample selection bias can occur since the observations of the second outcome are not a random sample from the population (Heckman, 1979).

An econometric approach to deal with this problem is the bivariate probit model with sample selection (also called censored probit or double probit). This model is based on the idea of the prominent Heckman's selection model (van de Ven & van Praag, 1981). A bivariate probit model with sample selection has also been used by Kongaut and Bohlin (2016) to analyze smartphone usage and mobile broadband adoption in Sweden. Following Kongaut and Bohlin (2016), this study observed three types of observations:

- (1) A farmer does not adopt a mobile device ($y_1 = 0$).
- (2) A farmer adopts a mobile device but does not use mobile internet ($y_1 = 1, y_2 = 0$).
- (3) A farmer adopts a mobile device and uses mobile internet ($y_1 = 1, y_2 = 1$).

Thus, these three possible types of observations in the sample have the following probabilities:

$$y_1 = 0, Pr(y_1 = 0) = \Phi(-x_1\beta_1), \tag{1}$$

$$y_1 = 1, y_2 = 0, Pr(y_1 = 1, y_2 = 0) = \Phi(x_1\beta_1) - \Phi_2(x_1\beta_1, x_2\beta_2, \rho), \tag{2}$$

$$y_1 = 1, y_2 = 1, Pr(y_1 = 1, y_2 = 1) = \Phi_2(x_1\beta_1, x_2\beta_2, \rho), \tag{3}$$

Taking these probabilities into account, the following log-likelihood function can be generated:

$$lnL = \sum_{i=1}^N \{y_{i1}y_{i2}ln\Phi_2(x_{i1}\beta_1, x_{i2}\beta_2, \rho) + y_{i1}(1 - y_{i2})ln[\Phi(x_{i1}\beta_1) - \Phi_2(x_{i1}\beta_1, x_{i2}\beta_2, \rho)] + (1 - y_{i1})ln\Phi(-x_{i1}\beta_1)\}, \tag{4}$$

where Pr denotes the probability that a farmer makes a binary decision, y represents the dependent variables for the selection and outcome equation, x is the vector of independent variables for both equations, β is the estimated coefficients of the independent variables, Φ is a cumulative of the unit-normal distribution function, and ρ denotes the correlation between the errors of both equations. Figure 1 illustrates the sample selection process of the presented model.

As pointed out by Sartori (2003) Heckman models are usually estimated with an instrument variable in the selection stage which is not used in the outcome stage. The coefficients in the model are identified without this extra variable. However, since identification in that case rests solely on the parametric assumption of bivariate normality and the absence of omitted variable bias, Sartori (2003) emphasized that it is not recommended to use the estimation technique with the same explanatory variables in both equations. Hence, “[...] a researcher left with an unhappy choice: to dredge up an extra explanatory variable for the selection equation [...] or to identify only from distributional assumptions about the residuals” (Sartori, 2003, p. 112). To account for this issue, an anonymous referee suggested comparing the results of the proposed model with results of a probit model, a bivariate probit model with sample selection without the instrument variable and a Sartori selection model (Sartori, 2003). The results are mutually supportive and therefore prove the robustness of the model. Table A2 provides an overview for the results of the models.

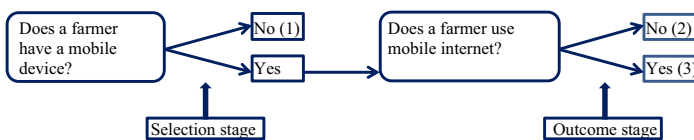


FIGURE 1 Sample selection process of the bivariate probit model with sample selection for the adoption of mobile internet by German farmers. Presented are the three possible observations. Source: Authors' illustration [Color figure can be viewed at wileyonlinelibrary.com]

3.2 | Data collection and sample

The analysis of German farmers' mobile internet adoption is based on data collected through computer assisted telephone (CATI) and web interviews (CAWI) with personalized links in 2016 by the Kleffmann Group². Eight-hundred and twenty-nine farmers were surveyed, of which 14 were excluded from the analysis due to missing values. The collected data was sampled to be representative in terms of distribution among age and farm size classes³ based on number of farms. Furthermore, the data set was representative for regional distribution and economic orientation (diversification; Destatis, 2014; German Farmers' Federation, 2014). Table 2 shows the summary statistics for all variables included in the econometric analysis. On average, 66% of the farmers have an internet-enabled mobile device (smartphone and/or tablet). Of these, 55% use mobile internet in the agricultural context. In 2016, 56% of the German population accessed mobile internet via a smartphone and/or a tablet (Statista, 2018), which is almost identical to the share of German farmers who used mobile internet via such mobile devices. With respect to sociodemographic variables, the average respondent is 49 years old and 89% of the respondents are male. Seventeen percent of the surveyed farmers have a university degree. The farm size in hectares (ha) ranged from 20 to 3,700 with a mean of 125 ha. Farm diversification was measured with the Berry index (Berry, 1971). If the Berry index approached 1, this indicated a high degree of diversification. For the sample, the average Berry index was 0.25⁴. Table 2 also includes information about the regional distribution of the farms across Germany. For instance, 25% of the farms are located in the Northern federal states of Germany. The participating farmers were also asked to indicate their agreement or disagreement with two statements using equally spaced five-point Likert scales. To measure innovativeness, the farmers were asked if they were interested in testing new technological innovations, which they on average slightly denied (2.26). Next, those polled were asked if they feel well-informed to avoid dangers on the internet, which on average they also slightly denied (2.70). Following the framework of Kongaut and Bohlin (2016), the frequency of fixed internet use in the adoption stage of a mobile device (but not in the outcome stage) was measured to account for the sample selection method presented in the previous section. Seventy-four percent of the interviewed farmers use fixed internet daily.

4 | EMPIRICAL RESULTS AND DISCUSSION OF RESEARCH HYPOTHESES

Table 3 shows the estimation results of the bivariate probit model with sample selection, which was estimated using the STATA software version 14. A Wald test of the model was highly statistically significant ($p < .01$), rejecting the null hypothesis of simultaneous equality to zero of the chosen coefficients. The Likelihood ratio test of $\rho = 0$ was rejected at the 1% significance level. This result indicated that the use of the sample selection method was necessary.

The results from the selection stage suggest that farmers who use fixed internet on a daily basis are more likely to adopt an internet-enabled mobile device since the coefficient is statistically significant and positive. This is in line with the results of Kongaut and Bohlin (2016). Furthermore, younger farmers and respondents with a university degree are more likely to adopt a mobile device. This parallels the results of Kim, Briley, and Ocepek (2015) and Zickuhr (2013) with regard to the adoption of smartphones and tablets, respectively. No correlation of mobile device adoption with gender, farm size, and farm diversification was found. Table 4 at the end of this chapter gives an overview of the results of the upcoming hypotheses testing.

²Farmers' addresses were chosen randomly by the Kleffmann Group to fulfill the sample quotas regardless of CATI or CAWI. First, the farmers were invited to take part in the survey via e-mail. If a response was missing, the farmers were asked via telephone. Then, the farmer could choose if they wanted to complete the interview via telephone or if they wanted to participate solely online at a later time. Thus, the interview method has no effect on the sample and a bias in the sample regarding internet affinity can be excluded.

³Farms with less than 20 hectares were excluded from the survey.

⁴The Berry index was obtained by calculating $B_i = 1 - \sum p_j^2$, where B_i denotes the Berry index for the farm i and p_j denotes the share of each farm activity j in the total turnover.

TABLE 2 Description of all variables included in the econometric analysis ($n = 815$)

Variable	Description	Mean	SD	Min	Max	
Dependent variables						
Mobile device	=1 if a farmer has an internet-enabled mobile device; =0 if otherwise	0.66	-	0	1	
Mobile internet ^a	=1 if a farmer uses mobile internet; = 0 if otherwise	0.55	-	0	1	
Independent variables for hypotheses testing						
H1a	Age	Farmers' age in years	48.72	11.17	16	85
H1b	Gender	=1 if male; =0 if female	0.89	-	0	1
H1c	Education	=1 if a farmer holds a university degree; =0 if otherwise	0.17	-	0	1
H1d	Innovativeness ^b	"As soon as a new technological innovation is launched in the market I am very interested in testing it."	2.26	1.07	1	5
H2	Familiarity with internet risks ^b	"I am well enough informed to avoid the dangers of the internet."	2.70	1.12	1	5
H3a	Farm size	Farm size in hectares arable land	124.86	257.37	20	3,700
H3b	Region					
	East ^c	Farm is located in the East of Germany	0.07	-	0	1
	North ^d	Farm is located in the North of Germany	0.25	-	0	1
	South ^{e,f}	Farm is located in the South of Germany	0.42	-	0	1
	West ^g	Farm is located in the West of Germany	0.26	-	0	1
H3c	Berry index	Measurement of farm diversification	0.25	0.22	0	0.77
Control variable						
Daily internet use	=1 if a farmer uses internet daily; =0 otherwise	0.74	-	0	1	

Source: Authors' own calculations.

Abbreviation: SD, standard deviation.

^aMean and SD shown as a ratio for mobile device = 1.

^bLikert scale 1 = strongly disagree; 5 = strongly agree.

^cSouth is set as the base category in the econometric analysis.

^dNorth = Schleswig-Holstein, Lower Saxony, and Mecklenburg Western Pomerania.

^eEast = Brandenburg, Saxony, Saxony-Anhalt, and Thuringia.

^fSouth = Baden-Württemberg and Bavaria.

^gWest = North Rhine-Westphalia, Hesse, Rhineland Palatinate, and Saarland.

4.1 | Research H1a-d

H1a addresses the effect age has on mobile internet adoption. The coefficient is statistically significant with a negative sign, indicating, *ceteris paribus*, that increasing age is negatively correlated with mobile internet adoption. Hence, H1a cannot be rejected. This result is in accordance with aforementioned studies about mobile internet adoption and internet adoption in agriculture. Younger farmers may have a greater interest in the usage of new technologies as also pointed out by Armeij, Vladar, and Pereira (2011) for the general population. Furthermore, skills to work with information technologies and mobile devices are likely to be better among younger adults in general (Gerpott, Thomas, & Weichert, 2013b). In line with that, Woodburn, Ortmann, and Levin (1994) showed that older farmers have less experience with computers. This holds also true with respect to smartphones (Rose et al., 2016). Furthermore, younger farmers have less experience in agriculture (Tamirat et al., 2018). Younger farmers might use mobile internet as an additional source of information for decision-making. In conclusion, younger farmers are more likely to adopt mobile internet.

TABLE 3 Results of the bivariate probit model with sample selection of mobile device and mobile internet adoption for German farmers ($n = 815$)

Variable		Mobile device adoption (selection stage)		Mobile internet adoption (outcome stage)	
		Coefficient	SE	Coefficient	SE
	Daily internet use	0.7803***	0.0986	-	
H1a	Age	-0.0219***	0.0044	-0.0202***	0.0055
H1b	Gender	0.0200	0.1578	0.0718	0.1666
H1c	Education	0.3179**	0.1335	0.0297	0.1347
H1c	Innovativeness	-		0.1919***	0.0496
H2	Familiarity with internet risks	-		0.0955**	0.0463
H3a	Farm size	0.0001	0.0002	0.0004*	0.0002
H3b	Region ^a				
	North	-		0.3345***	0.1267
	East	-		0.0740	0.2090
	West	-		0.4798***	0.1263
H3c	Berry index	-0.1077	0.2106	-0.1101	0.1347
	Constant	0.8807***	0.2890	0.4165	0.3382
	$\text{atanh}(\rho)$	-		-1.3407***	0.2809
	ρ	-		-0.8718	0.0674
	Likelihood ratio test for $\rho = 0$	20.41***			
	Wald χ^2	41.66***			
	Log-likelihood	-767.77			

Source: Authors' own calculations.

Abbreviation: SE, standard error.

^aSouth was set as the base category in the econometric analysis.

* $p < .10$.

** $p < .05$.

*** $p < .01$.

H1b postulates gender differences concerning mobile internet adoption among farmers. The coefficient has the expected sign but not statistically significant at a 10% significance level. Hence, the study cannot support H1b that gender is correlated with mobile internet adoption, *ceteris paribus*. This is in line with the regression results of Gerpott, Thomas, and Weichert (2013b). Even though the literature suggests that men are more enthusiastic about new technologies in general (Doss & Morris, 2000) and mobile technologies specifically (Jiang, 2008), Gerpott, Thomas, and Weichert (2013a) suggested in their study by comparing mobile internet adoption statistics over a certain period of time that the gender divide is narrowing fast. Ertiö and Räsänen (2017) found statistical evidence for gender being no longer important for mobile internet adoption by comparing the regression results from 2012 and 2014. This might explain the fact that no correlation between farmers' gender and mobile internet adoption was also found in this study. Hence, male and female farmers have equal chances when it comes to adopting mobile internet.

In light of H1c, the influence of farmers' education on mobile internet adoption was tested. The coefficient has the expected sign, but is not statistically significant at a 10% significance level. Hence, the study cannot support H1c that

TABLE 4 Overview of the hypothesis testing results

Variable	Hypothesis	Support H ₀
H1a Age	Older farmers are less likely to adopt mobile internet.	Yes
H1b Gender	Male farmers are more likely to adopt mobile internet.	No
H1c Education	More highly educated farmers are more likely to adopt mobile internet.	No
H1d Innovativeness	More innovative farmers are more likely to adopt mobile internet.	Yes
H2 Familiarity with internet risks	Farmers, who believe to be well-informed about the dangers of the internet, are less likely to adopt mobile internet.	No
H3a Farm size	Farmers from larger farms are more likely to adopt mobile internet.	Yes
H3b Region	Location of the farm in the southern region of Germany is negatively correlated with mobile internet adoption.	Yes
H3c Berry index	Diversification of the farm is positively associated with mobile internet adoption.	No

Source: Authors' own illustration.

farmers' education is associated with mobile internet adoption, *ceteris paribus*. The results are in line with Jiang (2008), but contradict the results from aforementioned studies that showed a positive relationship between education and mobile internet adoption. However, education is positively correlated with mobile device adoption, *ceteris paribus*, as shown in the third column of Table 3. Thus, if a farmer is able to handle a smartphone or tablet in general due to his formal education, he is already empowered to work with mobile internet. Nevertheless, an effect of education on mobile internet adoption is conceivable since education enables a farmer to process information more easily (Poolsawas & Napasintuwong, 2013). Furthermore, educated farmers may also have a greater demand for information (Carrer, de Souza Filho, & Batalha, 2017). Hence, more highly educated farmers could take more advantage of mobile internet use for information gathering. Nevertheless, education is not correlated with mobile internet adoption according to our results.

The effect of a farmers' innovativeness on mobile internet adoption was tested with H1d. As expected, innovative farmers are, *ceteris paribus*, more likely to adopt mobile internet since the coefficient is positive and highly statistically significant. Hence, the study cannot reject H1d. This result is congruent to the results of Li et al. (2007). Their results show that farmers' self-reported innovativeness is positively correlated with a positive attitude towards mobile commerce adoption (Li et al., 2007). The results are also in line with studies dealing with technology adoption outside of agriculture (e.g. Thong, 1999) since innovative individuals adopt new technologies and products more quickly than others (Morrison, Roberts, & Midgley, 2004). Hence, innovative farmers adopt mobile internet more quickly than other farmers.

4.2 | Research H2

H2 addresses farmers' perceived degree of being informed about dangers on the internet. The coefficient does not have the expected positive sign and is statistically significant. Thus, the study cannot reject H2 that farmers' perceived degree of being informed about dangers on the internet is correlated with mobile internet adoption, *ceteris paribus*. Even though there might be no monetary damage, violation of users' privacy is a major concern for many internet users (Lee, 2009). Furthermore, most farmers use the internet and its applications not only for private use, but mainly for business purposes (Mishra et al., 2009). Hence, they not only handle personal information but also business-related information on the internet, which can be considered highly sensitive. Intuitively, it could be expected that farmers who are aware about dangers of the internet are less likely to use mobile internet since they want to maintain their privacy

and ensure safety of business-related data. The contradicting results of our study could be explained as follows: A well-informed farmer might also be well enough informed to establish appropriate measures to ensure their safety while using the mobile internet and therefore is more likely to use mobile internet. For instance, a well-informed farmer screens websites or applications for certificates before using them. Certificates have been shown, for instance, to reassure individuals and therefore increase the possibility of online purchases (Jiang, Jones, & Javie 2008). Fecke, Danne, and Musshoff (2018) also showed that agribusiness using e-commerce should consider establishing a seal or certificate to increase farmers' trust. Furthermore, the results also imply that training courses with respect to digitalization for farmers should clarify risks using the internet and how to establish appropriate safety measures to encourage a farmer to use mobile data services. Michels et al. (2019) also showed that farmers have an interest in aspects of data security in training courses for digitalization.

4.3 | Research H3a–c

H3a–c address the influence of farm characteristics on mobile internet adoption. As expected, farm size is positively correlated with mobile internet adoption. The coefficient has a positive sign and is statistically significant on a 10% significance level. Hence, the study cannot reject H3a that farm size is associated with mobile internet adoption, *ceteris paribus*. Larger farms might face more multifaceted decisions and have a higher degree of organization complexity (Baker, 1992). Hence, mobile internet can be used to organize farm business duties, for instance banking and acquisition of operating funds for farming. Furthermore, employees and consultants can be contacted via mobile internet-based messenger services (Fecke, Michels, von Hobe, & Musshoff, 2018). Mishra et al. (2009) also pointed out that farmers from larger farms might have a higher demand for information. Hence, farmers from larger farms might use mobile internet for gathering information faster. In particular, mobile internet enables a farmer to reach, for instance, weather and price information almost independent from time and location. To sum it up, farmers managing larger farms have higher chances of adopting mobile internet.

Farm location is expected to be correlated with mobile internet adoption, which was tested with H3b. A post estimation joint significance test shows that the coefficients for farm location are equal to zero, *ceteris paribus*. The test is statistically significant ($\chi^2(3) = 16.17, p < .01$) rejecting the null that the coefficients are jointly statistical insignificant. Thus, the study cannot reject H3b on the whole. The southern region was set as the base category in the initial econometric analysis. The model shows no statistical significant difference between farmers who have their farms located in the eastern region compared with farms located in the southern region. However, farmers located in the South of Germany are less likely to adopt mobile internet compared with their northern and western colleagues, *ceteris paribus*. Srinuan et al. (2012) proposes differences in the digital infrastructure as a reason for varying adoption behavior for mobile internet. Furthermore, Hennessy, Läpple and Moran (2016) pointed out that regional location can be seen as a proxy for internet access. With respect to mobile broadband coverage, data provided by TÜV Rheinland (2017) reveal that UMTS and LTE coverage in the South of Germany is considerably less compared with the other regions of Germany (Table 1, Appendix A) which could potentially explain the results. Furthermore, cultural differences like more conservatism of farmers in the southern parts of Germany could be a barrier for innovation adoption like mobile internet. However, this was not explicitly considered in this study but it can be concluded that location of the farm influences mobile internet adoption.

Finally, H3c deals with the influence of farm diversification on mobile internet adoption. The model indicates that farm diversification is not associated with mobile internet adoption. Hence, the study cannot support H3c that farm diversification is positively correlated with mobile internet adoption, *ceteris paribus*. This finding is in line with Amponsah (1995) for the adoption of computers. Nonetheless, a positive correlation of farm diversification with mobile internet adoption would be conceivable since diversified farms might have higher demand for information and might use mobile internet for multiple production purposes and information gathering. Nevertheless, the results suggest that mobile internet adoption is not correlated with farm diversification.

5 | CONCLUDING REMARKS

Nowadays, mobile internet is widespread and adoption rates are still rising. In terms of agriculture, mobile internet can be helpful, for instance, to gather information and to implement smart farming technologies. This can lead to a reduction of costs and minimization of the ecological footprint of agriculture. Bearing this in mind, the study gives an insight into mobile internet adoption in agriculture by analyzing a representative data set of 815 German farmers. The study applied a bivariate probit model with sample selection to analyze key factors affecting the adoption of mobile internet. The results show that a farmer's age and the farm size are associated with mobile internet adoption.

Furthermore, the results show that farm location is correlated with mobile internet adoption of farmers. Policy makers may want to consider further expansion of mobile broadband coverage in rural areas. The results can potentially underline German farmers' demand for faster internet services in rural areas (German Farmers' Federation, 2017). To gain further insights, farmers' location and satisfaction with mobile broadband coverage could be considered instead of farm location solely. However, the reader should be cautioned that also the cultural differences (traditionalism or conservatism) of southern farmers could be a barrier of adoption, too.

Counterintuitively, farmers, who feel well-informed about dangers of the internet are more likely to adopt mobile internet. The results could be explained by the fact that well-informed farmers might have established safety measures to account for possible risks. Implications for this result are twofold: Aspects of digitalization should be included in the apprenticeship to make farmers aware of potential risks using the internet. In line with that, information about measures to ensure safety while being online should also be provided. Moreover, providers of farm equipment that rely on mobile internet (e.g. precision and smart farming technologies) should recognize farmers' security concerns and strive for clarification of risks associated with mobile internet to reduce hesitation of adoption. This could also be achieved by establishing certificates or seals.

Providers of farm equipment who integrate with mobile internet could also use this study for the coordination of marketing activities. According to results in the field of precision agriculture young and innovative farmers from large farms represent the target group of marketing activities since they are most likely the adopters (Aubert et al., 2012; Paustian & Theuvsen, 2017). For instance, providers and suppliers of precision and smart farming technologies could focus on mobile advertising to reach their core group since these results suggest that young and innovative farmers from larger farms are also more likely to use mobile internet. In line with that, providers could highlight the possibility to integrate mobile devices and internet with these technologies for this target group.

One limitation of the study is that the data set was collected in 2016. However, this article offers several points of departure for other research projects. For instance, this study could be replicated in other countries, especially in developing countries. Farmers' awareness and familiarity with specific internet risks (e.g. phishing) should be analyzed in depth as well. It would also be worthwhile to investigate how farmers specifically integrate mobile internet and relevant internet content or related applications into their farm business duties. Furthermore, it could be interesting how mobile and stationary internet use differs in terms of the retrieved information relevant to the farm business.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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