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AGRICULTURE IN CHANGE: EVALUATION OF FACTORS INFLUENCING THE ADOPTION OF SMART FARMING TECHNOLOGIES IN PORTUGAL

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Abstract

Recent developments in technology, such as Smart Farming Technologies ("**SFT**"), have the potential of revolutionizing agriculture. However, the level of adoption falls short of expectations, implying the importance of understanding the drivers of and barriers to technology adoption. Based on interviews with sector experts and field survey data, this paper analyses factors that may condition the adoption of SFT in Portugal. The logistic regression shows the importance of cost of investment, trialability of the technology, the awareness of available training programs and external financing, as well as the age and education of farmers for the adoption of SFT.

Keywords

agriculture; portugal; technological innovations; smart farming; smart farming technologies; technology adoption; farmers' perceptions; training program; farmer's age; farmer's education.

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1. Introduction

Agriculture in Portugal has undergone extensive structural changes in recent decades and is further expanding its importance. In 2019, agriculture represented around 2.1% of Portugal's GDP, with a share of 10.6% in exports, and employed 6% of the active population (World Bank 2019; European Commission ("**EC**") 2020a). The average increase in gross value of agricultural production between 2013 and 2018 in Portugal amounted to 3% per year (Instituto National de Estatistìca ("**INE**") 2019). The sector is dominated by small to medium size farms with an average size of 13.7 ha (INE 2019). The sector currently faces numerous challenges such as the consequences of unprecedented variations of the climate, increasing competition from large agro-enterprises, extended urbanization and aging (Calicioglu et al. 2019). Multiple studies highlight the negative impact of climate change on agriculture, where farmers will see their yield decline as a consequence of increased temperatures and changes in water availability (Morton 2007; G. C. Nelson et al. 2010). Portuguese farmers, because of Portugal's geographical situation and their socio-economic characteristics, are vulnerable to climate-related events such as drought, which directly impact soil fertility and maturation periods (Nunes et al. 2019). At the same time, price pressure and food demand have grown at a rate that local production levels have been difficulty to keep up with (FAO 2018).

Caught in between a rock and a hard place, farmers are forced to look out for new technologies, applications and solutions to more productively and efficiently exploit available resources. Global institutions have recognized the need to transition to sustainable and data-driven farming, which requires investment in technological innovation, strategic use of economic incentives and, in particular, behavioural changes (Rosegrant et al. 2014; EC 2017a; United Nations 2019). It is in the response to these challenges that Smart Farming ("**SF**") has gained prominence, playing a central role in transitioning to a digital and sustainable farming future. SF is a new approach to farming that is based on the collection and processing of data relevant to the farmer's production activity obtained from a set of Smart Farming Technologies ("**SFT**") including farm management information systems, agricultural automation and the use of robotic appliances[1] (EC 2014). These technologies not only allow for a "more efficient application of inputs (seeds, fertilizers, chemicals, water, fuel and labour), increased work speed, comfort and enhanced flexibility on the farm" (Balafoutis et al. 2017), help achieve higher output but also represent an important tool for achieving the United Nations Sustainable Development Goals ("**SDG**")[2] (Đurić 2020).

To facilitate their implementation and to better understand their benefits, SFT have been the subject of extensive studies in Europe. Despite this body of studies, studies related to the adoption of SFT in Portugal have remained limited. This research project aims at exploring adoption behaviours with regard to SFT in Portuguese agriculture. Its scope is targeting all types of crop producers in Portugal irrespective of their size and location, but excludes livestock producers and fishing, as the latter use different types of technologies in their sectors. The research model used in this study draws on established innovation adoption literature and expert interviews from which several hypotheses are developed and that are tested through data surveys solicited from Portuguese farmers. Understanding the factors that have an impact – beneficial or adverse – on the adoption decision may help policymakers and developers of SFT to design suitable incentives taking into account these impacts.

This study is divided into eight sections. Section 2 provides an overview of smart farming technology. Section 3 defines the research model, while Section 4 presents the empirical model. Section 5 and 6 present and discuss the empirical results. The study ends in Section 7 and 8 setting forth suggestions for further research, limitations and conclusions.

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[1] These elements are referred to in the declaration of cooperation on „A smart and sustainable digital future for European agriculture and rural areas" signed in April 2019 by 24 EU countries. Available here: https://ec.europa.eu/digital-single-market/en/news/eu-member-states-join-forces-digitalisation-european-agriculture-and-rural-areas.

[2] SFT have the potential to advance the following SDG: SDG 2 – Zero hunger; SDG 6 – Availability and sustainable management of water; SDG 8 – Decent work and economic growth; SDG 9 – Industry, innovation and infrastructure; SDG 11 – sustainable cities and communities; SDG 12 – Responsible consumption and production; SDG 14 and 15 – Life on land and below water; and SDG 17 – Partnership for the goals.

2. Smart Farming Technology

Digital agriculture technologies incorporate information and communication technologies into the agricultural production systems (Pivoto et al. 2018; Walter et al. 2017). The infant stage of SF dates back to the middle of the 90's (Mulla 2013) and derives from Precision Agriculture ("**PA**"), which is the management of spatial and temporal variation in the soil, crop and atmosphere using information and communication technologies in order to increase profitability and reduce environmental impact (Fountas 2005). In addition to PA, SF further incorporates aspects of data analytics, generating large volumes of data, and the Internet of Things[3] ("**IoT**"), providing enhanced connectivity in the production process (Wolfert et al. 2017). SFT combines both enhanced knowledge of real-time agricultural production conditions and farm work processes adapted to such knowledge. The use of SF hardware and software technologies constitutes the management cycle shown in Figure 1 (Balafoutis et al. 2017):

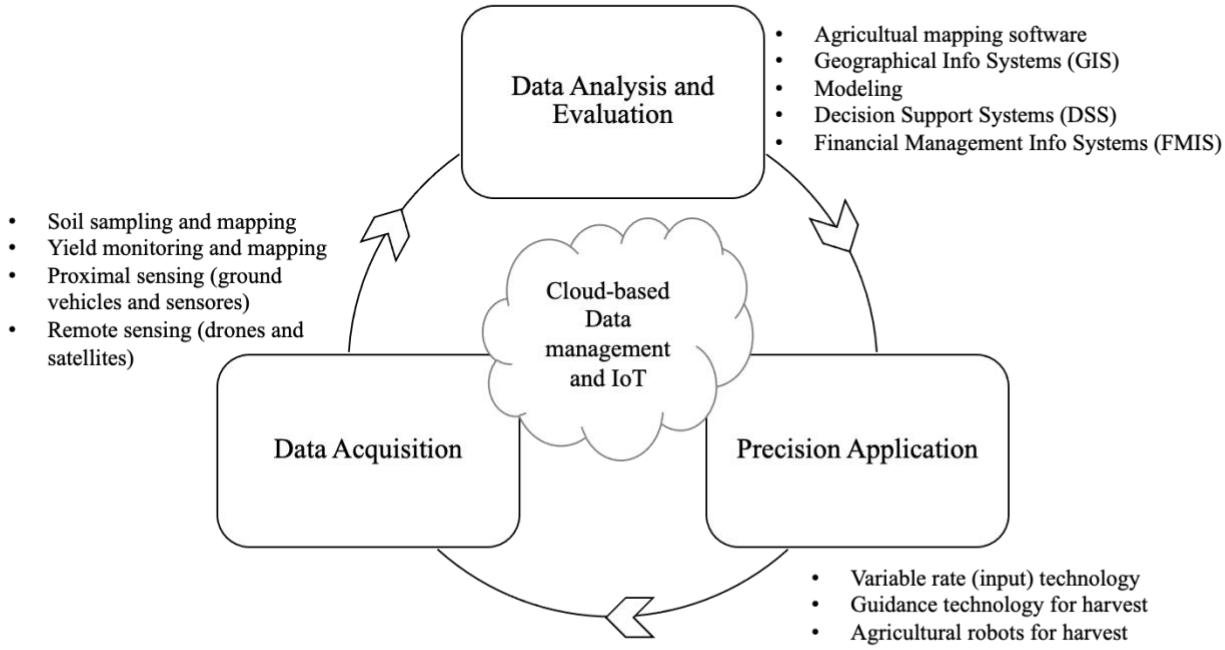
- Data acquisition: this category contains all yield and soil surveying, mapping, navigation and sensing technologies, satellite and drone technologies
- Data analysis and evaluation: these technologies range from simple computer-based decision models to complex farm management and information systems including many different variables
- Precision application: this category contains all application technologies, ranging from variable rate application, guidance technologies to agricultural robots.

For instance, in situ field sensors complement data gathered from satellites or drones, providing enriched real-time information about different environmental condition such as the soil conditions, weather, temperature, and crop growth (Bacco et al. 2019). Data collected via IoT-enabled technologies is processed and transformed into decision-making tools, which allows

[3] IoT refers to a "network of physical devices embedded with electronics, software and connectivity that collect, process and share data for monitoring and control" (Charania and Li 2020).

farmers to effectively apply precision application technologies e.g. for applying fertilizers, pesticides and irrigation where they are needed (Wolfert et al. 2017; Jouanjean et al. 2020). Guidance and robotic technologies assist the farmer during harvest and data from harvest are feed into the data acquisition systems as a basis for the subsequent production cycle.

Figure 1. The smart farming management cycle



Loures et al. (2020) have tested the impact of using remote sensing techniques in small farms (less than 50 ha) located along the Portuguese-Spanish border. They concluded that an efficient use of these techniques improves crop productivity and farm profitability, promoting sustainable agriculture both in ecological and economic terms. The Food and Agriculture Organization ("**FAO**") also views that, if implemented correctly, SF enables farmers to achieve "better yields by optimizing farm management, reducing the use of fertilizers, pesticides and water, and also contributing to better and more sustainable outcomes" (FAO 2020).

The European Union ("**EU**") has made the adoption of SFT a strategic priority under its Common Agricultural Policy[4] ("**CAP**") and has "been actively undertaking R&I [Research &

[4] The CAP is a common policy for all EU countries. It is managed and funded at European level from the resources of the EU's budget to support farmers and improve agricultural productivity. Available here: https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/cap-glance_en#title.

Innovation] activities laying the ground for digitalised and data-empowered European agriculture and rural areas" (EC 2019a).[5] Despite this strategic priority, statistics show that in the EU no more than 24% of farmers use some kind of SFT (EC 2017b) while in Portugal the adoption rate is only 0,3% of farmers (INE 2021). Although some SFT are mature enough and increasingly available, and the benefits are documented and validated, in the EU, SF is "experiencing difficulties in translating into smallholder farmer and civil society actions as well as new policy directions" (De Pinto et al. 2020). This study attempts to shed some light on certain factors that shape the farmers' decisions to adopt SFT.

3. Conceptualizing a SFT adoption model

Broad theoretical and empirical literature has evolved in the area of technology adoption that attempts to analyse observed adoption patterns. Given that technology uptake is a complex process, influenced by multiple factors, a research model was designed for this study taking into account the past literature. Building on this literature provides sound theoretical considerations for the hypotheses of this study that can be tested empirically. Seven experts ("**Experts**") with knowledge and insight in agriculture in Portugal were interviewed. These Experts include a government representative, an agriculture consultant, a professor of agronomy, an SF provider, a representative of a farmers' associations and several farmers. They contributed to the preparation of the model by highlighting the specific Portuguese context. This section aims to formulate hypotheses on factors that may influence adoption decisions by Portuguese farmers.

a. Utility and technology adoption

Traditional economic theory suggest that individuals base their decisions to adopt a technology on the expected "utility" derived from the technology as individuals seek to

[5] A comprehensive list of EU-funded R&I projects towards increasing digitization in the farming sector is available here: https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/factsheet-agri-digital-transformation_en.pdf.

maximize their utility (Edwards-Jones 2006). Indeed, the return on investment to the individual, taking into account all costs of adopting and using the new technology, is a key factor of adoption (Foster and Rosenzweig 2010). The utility can be measured by applying the diffusion of innovation theory, developed by Rogers (1962). This theory focuses on the perceived benefits and costs of an innovation – although this is not necessarily an objective assessment of these properties. As objective assessments may not be feasible (at least in the short run), measurement of perception is likely to be more realistic and insightful than after-the-fact objective assessments when explaining adoption patterns (Aubert et al. 2012). In the agricultural context, it was found that farmers' perception of the economic benefit and cost implications are major factors in determining adoption and use intensities of SFT (Adesina and Zinnah 1993; Adrian et al. 2005; Aubert et al. 2012). In this model, it is hypothesized that each, the perception of benefits (H1) and cost (H2) will be positively correlated to the actual adoption of SFT. These assumptions were also confirmed in the Expert interviews.

H1. *The greater the perceived benefit of SFT adoption the more likely they will be adopted.*

H2. *The greater the perceived cost of SFT adoption the less likely they will be adopted.*

b. Learning and technology adoption

Recent literature has pointed to the role of learning as a key element in the adoption process (Foster and Rosenzweig 2010). In a setting in which a new technology is introduced, adoption barriers could arise where individuals are uninformed about its use and the potential returns derived from it. The literature in agriculture points out that learning of and understanding the benefits of a new technology is associated with experimenting with and trial use of such technology; a farmer having a better understanding of the benefits – in particular after having tried out or having experimented with the technology – is more likely to adopt a technology (Duflo et al. 2008). Furthermore, the Joint Research Commission ("**JRC**") of the EC (2014) found in its study that the lack of independent advisory services and training programs from governmental bodies, co-operatives and farmers' associations constitute barriers for the adoption of SFT. On the other hand, the easier the use of technology, the least the adoption should be dependent on a learning process and training programs. In this model, it is hypothesized that trialability of SFT (H3), ease of utilization of SFT (H4) and the awareness of available information and training programs (assuming that such information and training programs actually are available) (H5) have an impact on the adoption of SFT. These assumptions were also confirmed in the Expert interviews.

H3. *The greater the trialability of SFT the more likely they will be adopted.*

H4. *The greater the ease of utilization of SFT the more likely they will be adopted.*

H5. *The awareness of available information and training programs related to SFT increases adoption.*

c. Education and technology adoption

The literature suggest that education plays an important role in the adoption of new technologies, reflecting the pervasive finding that higher educated individuals are better able to decode and understand new and complex information faster and more efficiently (Nelson and Phelps 1966). In agriculture, higher education levels were found to positively impact decisions to adopt new technologies, as farmers having benefited from higher education are more likely to better understand and evaluate the information on new technologies, the way they are to be utilized and their benefits (Nelson and Phelps 1966; Reichardt et al. 2009; Baumgart-Getz et al. 2012). The less educated farmers, instead, remain cautious in adopting new technologies until they have clear evidence of their benefits and sufficient experience has developed at the industry level. Adoption of new technology is also impacted by the age of the farmer as younger farmers have a longer planning horizon, and their education tends to be higher – enhancing their skills required for understanding SFT (McBride and Daberkow 2003; Paxton et al. 2011). In this model, it is hypothesised that the education of a farmer (H6) and the age of the farmers (H7) have an influence on the adoption of SFT. These assumptions were also confirmed in the Expert interviews.

H6. *The higher the farmer's education level the more likely SFT will be adopted.*

H7. *The higher the farmer's age the less likely SFT will be adopted.*

d. Wealth and technology adoption

There is evidence from the literature that the income of an individual has an impact on the adoption of technologies (Foster and Rosenzweig 2010). As the acquisition costs typically have to be paid at a time when returns are still uncertain, less wealthy individuals with limited access to external financing are less likely to adopt new technologies. In agriculture, farmers face the risks of uncertain recurring returns and environmental uncertainties like weather variations (Feder et al. 1985). Despite these uncertainties, wealthier farmers are more likely to adopt new technologies because they have the financial means to accommodate those types of risk. Moser and Barrett (2003) have shown that farmers in Madagascar with a stable source of income are more likely to adopt and continue using a new rice production technology. Therefore, the absence of financing in any form (e.g. own savings, credits, subsidies, etc.) appears to make it less likely that a new technology will be adopted. The JRC confirms this finding, when it suggests that the lack of access to financing constitutes a barrier to the adoption of SFT (JRC et al. 2014). Furthermore, farm size is reported to have a similar effect on the adoption of new technologies, since larger farms are more likely to benefit from larger financial resources and economies of scale than smaller farms (Schimmelpfennig 2016; Caffaro and Cavallo 2019). In this model, it is thus hypothesized that a farm's financial strength (H8), farm size (H9) and awareness of available external financial resources (assuming that such financing is actually available) (H10) impact the adoption of SFT. These assumptions were also confirmed in the Expert interviews.

H8. *The bigger the farm's financial strength the more likely SFT will be adopted.*

H9. *The bigger the size of the farm the more likely SFT will be adopted.*

H10. *The awareness of available external financing for SFT increases adoption.*

e. Infrastructure and technology adoption

Other important components such as the physical environment and infrastructure may influence the user's behaviour to adopt a new technology. In the agricultural context, it was found that farmers' perception of compatibility with existing processes is a major factor determining adoption of SFT (Kernecker et al. 2020). In addition, the Experts interviewed noted the lack of a stable IT infrastructure, such as broadband access, in certain Portuguese rural areas as an adoption barrier for SFT. In this model, it is hypothesized that the perception of compatibility with existing equipment and operations (H11) and a weak IT infrastructure like low broadband access (H12) have an influence on the adoption of SFT.

H11. *The greater the compatibility of SFT with current equipment and way of operations the more likely they will be adopted.*

H12. *The lower the stable broadband connection, the less likely SFT will be adopted.*

The resulting research model consists of twelve hypotheses, which will be the predictor variables in the subsequent statistical analysis, with SFT adoption as the outcome variable.

4. Research methodology

In the context of this study, factors affecting a farmer's decision to adopt involves the collection of quantitative data and their statistical evaluation.

a. Data collection and variables measurement

Data collection on SFT adoption was carried out by means of a survey sent to farmers in Portugal. The survey was designed based on the hypotheses described in Section 3 each of which requires a specific and appropriate measurement method, which are summarized in Appendix A. The survey contains a mix of 25 closed-ended questions for a quantitative analysis (an English version of the survey is provided in Appendix B). In consideration of the variable types, the survey includes binary questions (e.g. yes/no), multi-item scale questions (e.g. five point Likert scales), single-choice questions, and multiple-choice questions.

The survey is divided into 4 sections. It starts off by asking farmers to indicate what type of crops they grow together with single-choice questions related to their farm and farmer characteristics (age, education level, farm size, farm income, years of experience). Afterwards, farmers' perception of specific SFT attributes (costs, benefits, ease of utilization, compatibility, trialability) is asked for by using a five-point Likert scale each, which allows the participants to rank the degree to which they agree with a statement (ranging from "strongly agree" to "strongly disagree). Each of the attributes contains three sub-questions/items. Then follow questions related to the general environment affecting the diffusion of SFT in Portugal (availability of stable broadband access, awareness of external financing, awareness of information and training programs) in the form of binary questions. The participants are asked to specify which of eight specific types of SFT (i.e., soil monitoring sensors, yield monitoring, satellite technology, drones, robotic farming machines, variable rate technology, farm management system, data analytics systems) they are aware of and have adopted, if any. The survey provides images of each of these SFT to ensure that the participants recognize which technologies are referred to. Farmers were assumed to have adopted SFT if at least one of the eight technologies was adopted. There is no weight attributed in case a farmer adopted more than one SFT. The survey was prepared, organized, and made available through the online platform SurveyMonkey.[6] The participants were informed that their responses will remain anonymous and can in no way be traced back to them. Requests to participate in the survey were submitted by email using databases such as ViniPortugal or Agroportal. In addition, multiple farmers' associations and cooperatives mentioned on the platform of the Portuguese farmer confederation[7] were requested by email to forward the survey to their members in order

[6] https://s3.amazonaws.com/SurveyMonkeyFiles/UserManual.pdf.
[7] https://www.cap.pt/associativismo/lista-de-associados.

to broaden the base of potential participants. The survey was sent in Portuguese and took approximately 5min to be completed. It was available in digital form from March 16th to April 16th, 2021.

In addition, Expert interviews had been conducted beforehand to develop a general understanding of the state of SF in Portugal that informed the survey. In preparation for the interviews, a structured guideline had been developed including socio-demographic, economic and political factors that may drive or restrain the adoption of SFT. More specifically, the Experts were asked for their views as to: (1) the importance of digitization and SFT in Portuguese agriculture, (2) factors motivating farmers to adopt SFT, (3) barriers to SFT adoption, (4) the role of institutions and politics to support farmers in the transition to SF and, (5) the future of Portuguese agriculture. Each interview lasted approximately for one hour.

The validity of the survey was determined by conducting multiple pre-tests with experts before submitting it in order to guarantee that the variables measure what they are intended to measure. The first was faculty from the department of economics of Nova Business School and Economics, who validated the appropriateness of the survey in terms of logic and convergence. Two subsequent validations took place with a representative of a farmers' association and a farm owner to ensure that the questions were clear, unambiguous and relevant from an agricultural point of view.

b. Data analysis

The data, to which the statistical analysis is applied, were collected during the one-month survey of a random sample of 183 participating farmers across Portugal. The data submitted had instances of incompleteness, such that only 102 complete responses could be used for the analysis. The data set was subjected to descriptive and inferential statistical analyses – see below section 5a. and 5b. The mean, median, variance, standard deviation, minimum and maximum values were examined for each variable in the data set. To further investigate the effect of predictor variables on the outcome variable, the data was entered into the SPSS software using a regression model (Field 2018). As the outcome variable is binary, meaning that the adoption of SFT takes two possible values (1=adoption or 0=not adoption), a binary logistic (logit) regression model is used to predict adoption given a set of predictor variables (Pituch and Stevens 2016). The logistic regression equation is provided in Appendix C (Pituch and Stevens 2016).

c. Assessment of reliability of Likert scale variables

The reliability of the different Likert scale variables in measuring internal consistency was assessed by measuring the Cronbach's alpha (Churchill Jr 1979). In order to quantify the variable as reliable, the Cronbach's alpha needs to be above 0.7 (Nunnally 1978). All items in the Likert scale variables meet the criteria of 0.7 Cronbach alpha and needed no modification (Appendix D).

d. Omitted Variable Bias

Before applying inferential statistics analysis, the grouping of predictor variables in the regression model is of importance to achieve numerically stable estimates and avoid common biases (Bursac et al. 2008). For instance, the grouping of variables in a regression model must be designed to avoid that an Omitted Variables Bias ("**OVB**") occurs. OVB occurs when a regression model leaves out one or more variables, known as confounding variables, that correlate with the outcome variable and with at least one of the predictor variables in the same group of variables (Angrist and Pischke 2009). Omitting confounding variables results in over- or underestimating the effect of certain predictor variables on the outcome variable. For example, past theories suggest that the education level of farmers has an impact on the adoption of SFT. In addition, it is found that younger individuals tend to be more highly educated in Portugal and are more likely to adopt SFT, making age a potential confounding variable (Appendix E illustrates the relationship). Leaving out the age variable that correlates with both education and SFT adoption might cause an estimation bias. To address OVB, the possible confounding variable must be included as a control variable in the regression model in order to control their impact on the outcome variable and other predictor variables (Skelly et al. 2012). For instance, the variable age must be included as a control variable in the same group as the education variable. In addition to avoiding OVB, intermediate variables i.e., variables in the causal pathway between predictor and outcome variables, need to be excluded in the same group of variables (Skelly et al. 2012). For this reason, this model, for example, avoids placing education and farm income within the same group of variables since education is found to increase an individual's income. Considering OVB and intermediate variable bias, the variables were regrouped in multiple regression models according to the hypothesis groups in section 3.

5. Data results

a. Descriptive findings

A total of 102 complete responses have been received. Table 1 provides an overview of the descriptive findings of the sample (for a deeper view on frequencies see Appendix F).

Table 1. Descriptive findings of the sample (n=102)

	Minimum	Maximum	Median	Mean	Std. Error of Mean	Std. Deviation	Variance
Age	1	4	3	2.51	.092	.931	.866
Education Level	1	3	3	2.52	.069	.700	.490
Farm Type	1	3	1	1.75	.089	.898	.806
Farm Size	1	7	3	3.22	.170	1.721	2.963
Farm Income	1	6	3	3.19	.171	1.728	2.985
Cost of investment	1	5	4	3.80	.099	1.005	1.011
Relative benefits	2	5	4	4.04	.079	.807	.652
Compatibility	1	5	4	3.64	.115	1.167	1.362
Difficulty of Utilization	1	5	3	3.11	.095	.964	.929
Trialability	1	5	4	3.59	.129	1.308	1.710
Stable Broadband Access	0	1	1	.75	.043	.432	.187
Financial Assitance	0	1	0	.31	.046	.466	.217
Information and Training Programs	0	1	0	.34	.047	.477	.228
Adoption of SFT	0	1	0	.42	.049	.496	.246

The median age class of farmers participating in the survey is 55-64 years i.e., the numbers of older farmers is relatively high; their mean education level is higher education, although unevenly spread among the age groups. Their mean farm size and annual farm income groups are 26 - 50 hectares and €25.001 - €50.000, respectively. The participants in the study are rather smallholders, managing the family farm for more than one generation. The three main crops produced in the sample are grapes (38%), corn (14%) and olives (10%).

Remarkably 97 farmers claimed being aware of some type of SFT, showing that the concept of SF is well known in Portugal. The main sources of information, through which farmers are made aware of the existence of SFT, appear to be the internet (13.4%), official tradeshows (13%), agriculture consultants (11.3%) and other farmers (11.1%). Even though almost all responding farmers are aware of some type of SFT, they are generally reluctant towards the adoption of SFT, with 58% non-adopters. Those farmers that adopted SFT, principally invested in soil (18%) and yield (16.5%) monitoring sensors and farm management systems (16%), which the Experts had described as low-cost technologies. In contrast, more expensive SFT, such as robotic farming machines (8.2%) and variable rate technologies (7.7%) are less likely to be adopted. The majority of Portuguese farmers perceives the cost of investment in SFT as high (64.7%) but acknowledges (73.6%) the various benefits that SFT entail, such as input savings, increases in yields and reduction of workload. Surprisingly, among those acknowledging the benefits, 49% are non-adopters. The majority (42.2%) is neutral as to the ease of utilization of SFT. The majority of farmers also perceives SFT as being compatible with their farm infrastructure and way of working (56.9%) and highlights that SFT can be used on a trial basis for long enough to test their benefits (58.7%).

Contrary to the Experts' views, 75.5% of farmers stated that they have stable broadband access at their farm.[8] 68.6% and 65.7% of farmers, respectively, were not aware of any external financing from any source (subsidies, credit, grants, tax advantages) for the adoption of SFT or any information and training programs related to SFT.

b. Hypothesis testing

In order to assess the research question, four different regressions are conducted. First, Table 2 contains the results of the logit regression model with the factors age of farmer and education level. As mentioned in section 4d., the model grouped the variables education and age in the same regression to avoid OVB. The first column contains the regression coefficients ("B"), which represents the log odds change in the outcome variable for one unit of change in the predictor variable while holding the other predictor variables in the model constant (Szumilas 2010). The "p"-value indicates whether the predictor variable contributes significantly to the occurrence of the outcome or not. Furthermore, as each ordinal variable has multiple categories (e.g. education variable includes primary school, secondary school and higher education), they have to be handled differently (Smith 2015a). For example, in Table 2 it can be seen that the ordinal variable education is represented by two dummy variables, primary education=1 and secondary education=2, while higher education (the last category) is the reference category against which the dummy variables are compared.

As hypothesized, Table 2 shows that the variables education (H6) and age (H7) are statistically significant predictor of the probability of SFT adoption (p-value below 0.05). Indeed, a young farmer below age 35, versus a farmer above age 65, increases the log odds of adoption by 2.5. Considering education, having completed a secondary school, versus a higher education institution, decreases the log odds of adoption by 1.171.

[8] It should be noted though that the survey used in connection with this model was send to Portuguese farmers by means of the internet. It can therefore not be ruled out that farmers without stable broadband access did either not receive the survey or that as a result of their weak IT infrastructure were unable to respond to the survey, leading to a biased result with regard to availability of infrastructure.

Table 2. Logit model education (Education level, Age)

	B	S.E.	Significance (p)
Age			0.045
Age (1)	2.500	1.236	0.043
Age (2)	1.985	1.173	0.091
Age (3)	1.227	1.148	0.285
Education Level			0.028
Education Level (1)	-1.807	1.169	0.138
Education Level (2)	-1.171	0.597	0.014
Constant	-1.500	1.135	0.186

Note: B stands for regression coefficient and S.E. for standard

Second, Table 3 focuses on the variables trialability of SFT, ease of utilization of STF and awareness of information and training programs. As hypothesized, the variables trialability (H3) and the awareness of information and training programs (H5) are significant predictors for the adoption of SFT. Considering trialability, farmers indicating disagreement with the possibility to test SFT on a trial basis are less likely to adopt SFT (B equal -3.696) than farmers indicating strong agreement. The awareness of information and training programs also represents an important factor of predicting adoption with a positive B indicating an increase in the log odds of adoption by a factor of 3.431, when the farmer is aware of or participated in any information and training program related to SFT. However, the variable perceived ease of utilization was not found to be significant in the study with a p-value above 0.05.

Table 3. Logit model learning (Ease of Utilization, Trialability, Information and Training Programs)

	B	S.E.	Significance (p)
Trialability			0.019
Trialability (1)	-22.393	12807.931	0.999
Trialability (2)	-3.696	1.449	0.011
Trialability (3)	-4.311	1.463	0.003
Trialability (4)	-0.951	0.81	0.24
Ease of Utilization			0.942
Ease of Utilization (1)	-18.369	20096.485	0.999
Ease of Utilization (2)	-1.026	1.627	0.528
Ease of Utilization (3)	-1.053	1.276	0.409
Ease of Utilization (4)	-0.714	1.318	0.588
Information and Training Programs	3.431	0.902	<0.001
Constant	0.861	1.175	0.463

Third, Table 4 analyses the variables farm income, farm size and awareness of available external financing. It should be noted that farm size and farm income are in the same regression model to avoid potential OVB as a larger farm may have larger financial resources. As hypothesized, the variable awareness of external financing (H10) is a significant predictor for the adoption of SFT. Indeed, the log odds of adoption increase by 1.373, when the farmer is aware of any external financing related to SFT. The variables farm size and farm income are not found to be significant for adoption in the study (leaving aside potential OVB).

Table 4. Logit model wealth (Farm Income, Farm Size, External Financing)

	B	S.E.	Significance (p)
Farm Size			0.170
Farm Size (1)	-1.108	1.289	0.390
Farm Size (2)	-1.189	1.148	0.300
Farm Size (3)	-0.431	1.155	0.709
Farm Size (4)	-0.079	1.247	0.950
Farm Size (5)	1.908	1.327	0.150
Farm Size (6)	1.433	1.385	0.301
Farm Income			0.289
Farm Income (1)	-0.427	1.060	0.687
Farm Income (2)	0.472	1.007	0.639
Farm Income (3)	0.421	0.970	0.664
Farm Income (4)	-1.208	1.010	0.232
Farm Income (5)	1.450	1.172	0.216
External Financing	1.373	0.556	0.014
Constant	-0.585	1.139	0.608

Fourth, Table 5 measures the variables perceived cost of investment in SFT, perceived benefits of SFT, compatibility of SFT with existing equipment and operations and stable broadband access. It should be noted that perceived cost of investment and benefits of SFT are grouped together to avoid potential OVB as cost of investment are likely an important factor in assessing the benefits of an adoption. As hypothesized, the variables cost of investment (H2) is a significant predictor of SFT adoption. Indeed, disagreeing with the proposition that SFT are a costly investment, increases the log odds of adoption by 4.488. However, the variables perceived benefits of SFT[9], compatibility of SFT with existing equipment and operations and access to stable broadband[10] are not found to be significant in the study.

Table 5. Logit model utility and infrastructure (Cost of investment, Benefits, Compatibility, Stable Broadband access)

	B	S.E.	Significance (p)
Cost of Investment			.001
Cost of Investment (1)	23.834	40192.969	1.000
Cost of Investment (2)	4.488	1.518	.003
Cost of Investment (3)	4.342	1.299	<.001
Cost of Investment (4)	1.924	1.178	.102
Benefits			.564
Benefits (1)	-17.229	28420.722	1.000
Benefits (2)	-.483	1.462	.741
Benefits (3)	.881	.802	.272
Compatibility			.103
Compatibility (1)	-19.843	26646.137	.999
Compatibility (2)	-3.697	1.456	.011
Compatibility (3)	-1.916	1.072	.074
Compatibility (4)	-.561	.762	.462
Stable Boradband Access	.573	.970	.555
Constant	-2.631	1.377	.056

6. Discussion of results

The study shows that the factors age, education, trialability of SFT, awareness of information and training programs, perceived cost of investment and awareness of external financing are significant predictors of adoption.

a. Age and education of farmers

The study shows that young farmers are more likely to adopt SFT than older farmers (see p. 17). According to the Portuguese national institute for statistics (2021), the average age of

[9] Perceived benefits of SFT appear non-significant in this study because the vast majority of participants agreed with the proposition that SFT are beneficial and approximately one half of that majority are non-adopters. It seems therefore to be a widely shared view that SFT generally speaking is a beneficial technology for farmers.
[10] See footnote 8 on page 17.

the Portuguese farmer is 64 years, making the ratio of young farmers[11] to older farmers the second lowest in the EU. The lack of young farmers is not an entirely new issue in Portugal, which has set to encourage a generational renewal in agriculture by facilitating the installation of more than 4.600 young farmers by 2023 under the CAP reform 2014-2020 (EC 2020). While the current average age of farmers in Portugal is generally adverse to the adoption of SFT, the pending generational renewal however is likely to favour the adoption of SFT in Portugal in the medium term.

Furthermore, a farmer with higher education is more likely to adopt SFT, then a farmer without such higher education (see p. 17). This finding is in accordance with Nelson & Phelps (1966), who state that a certain education – vocational training and higher education – allows individuals to decode and understand the functioning and benefits of SFT. The study also makes apparent that the younger the population of farmers, the higher their level of education. While in the bracket of below age 35, 87.5% of farmers have higher education. This percentage decreases to 55% in the bracket of age 51-65 and 13% in the bracket above age 65. This shows that Portuguese farmers tend to be well educated, but that age is an important factor in the educational level the farmers have gone through.

b. Trialability and training programs

A main finding in the study is that pre-adoption trialability of SFT (see p. 18) as well as the awareness of information and training programs for farmers with respect to SFT (see p. 18) are drivers for the adoption of SFT. It appears important, in order to boost the adoption of SFT, to broadly create awareness of available information and training programs for farmers. Generally speaking, a broad exchange of know-how on SFT (preferably bringing together all interested stakeholders including research institutes, universities, technology developers, consultants and farmers) that familiarize farmers with all (practical) aspects of utilizing SFT

[11] According to the EU a young farmer is a person below the age 40 (Zagata et al. 2017).

through on-farm demonstrations, experimentation stations and trial periods appears desirable. It should be noted that under the 2014-2020 CAP, Portugal allocated 1,7% of its total rural development budget to M01 (knowledge transfer and information actions), M02 (advisory services, farm management and farm relief services) and M16 (cooperation projects), but that these earmarked funds were still below the EU average of 3,6% (EC 2019b).

c. Financial situation

The results of the study show that certain aspects of farms' financial situations are important factors in the adoption of SFT. Relevant aspects include cost of investment (see p. 19) and awareness of external financing (see p. 19). The results show that the cost of investment remain an adoption barrier, suggesting that the availability of external financing is an important factor. It should also be noted that certain SFT already now are made available to farmers free of charge, including certain satellite imaging technologies related to soil monitoring. Where possible, free of charge services should be broadened to reduce adoption barriers, provided that full information and training with respect to these technologies are afforded to farmers. Furthermore, this study suggests that if the scope of low-cost SFT, like certain sensor technologies, were to be broadened, this should also have a beneficial effect on reducing adoption barriers (see p. 16). Finally, it is still paramount to create awareness of farmers that external financing for SFT, including low interest credit, subsidies and other incentives, are available.

d. Research contribution

The study concentrates on agriculture as an important area for IT applications. Digitization is becoming of increased importance in agriculture with IT-based technologies advancing. The findings of this study may provide assistance and guidance to further research and national planning of SF incentives in Portugal. Currently, Portugal holds the presidency of the council of the EU (from January 1st to June 30th, 2021), which represents a key opportunity to develop further strategies to facilitate the adoption of SFT under the CAP reform 2021-2027. The priorities under this CAP reform being innovation, knowledge transfer and the digitalisation of the agriculture sector, the hypotheses made in this study squarely fall within this scope of these priorities.[12]

7. Limitations and future research

It is recommended for future research to increase the sample size for a higher degree of significance in the statical analysis. This would allow to further investigate those factors that were not found significant in the study. For example, as described above in footnote 9, the variable benefits of adoption of SFT was not found to be significant. This result may have been caused by bias. A large number of participants may capture a higher number of participants that do not view SFT as beneficial to their business, unless a general view has developed that SFT are generally beneficial. Similarly, in the case of the use of Likert scale dummy variables, a larger sample size may avoid over-inflated regression coefficients (B) for one or more of these dummy variables and thus render them significant. For example, according to Table 3, only four participants marked "strongly disagree" in question ease of utilization of SFT. These same four participants also were non-adopters. The limited number of these responses has led to a largely overstated B rendering the dummy variable non-significant in this study.

As stated in section 4d., the potential effects of OVB on the outcome of the study are of concern. The ideal thought experiment would be to randomly assign characteristics (education level, age, farm income, farm size, etc.) to individuals and then measure whether these individuals adopt SFT as a function of these characteristics (Smith 2015b). This would allow to control for all potential confounding variables. However, in practice, these characteristics are not randomly assigned to individuals and will likely be corelated with other unobserved

[12] The program for the Portuguese Presidency of the Council of the EU is available here: https://www.2021portugal.eu/media/rohpisqf/portuguese-presidency-en.pdf.

characteristics. For example, an individual that runs a large farm may not just be wealthier, but also be more skilled. Therefore, the coefficient on farm size could reflect not only wealth but also skill. Another possible confounding variable is the political and economic stability of a country, which might provide favourable conditions for the availability of external financing and training programs, thus influencing their impact on the adoption of SFT. Additionally, the learning process might not only be affected by trialability and training but also by observing other farmers using SFT, making learning from other farmers a potential confounding factor to explain adoption. Future studies should identify possible further confounding variables.

Selection bias also presents an issue for the validity of the study, as it may fail to capture a representative sample of the population (Heckman 2010). Selection bias occurs when some members of a population are more or less likely to participate in the study. This is especially the case when the data collection method has limitations. For example, as described above in footnote 8, stable broadband access was not found to be significant. By including sample solicited by mail rather than solely through the internet, farmers without broadband access may participate in the study and may increase the significance of the variable broadband access.

As concerns available information and training programs for SFT and external financing, this study focuses on the farmers' awareness of such elements rather than their sufficient availability in Portugal. Further research should analyse the level of such factors including their availability in Portugal.

This study excluded the survey of issues related to data management such as data privacy, ownership and sharing on the uptake of SFT. These issues have become increasingly of concern for farmers (Jakku et al. 2019; Jouanjean et al. 2020). It cannot be excluded, that the lack of a regulatory framework for protecting agricultural data collection processes contribute to a farmer's reluctance to adopt SFT. This may particularly be the case where data collected on a farm are subsequently processed and analyzed by external processors of data.

8. Conclusion

Faced with the threats by climate change, growing price pressure and food demand, Portuguese agriculture may respond by adjusting its traditional production methods to data-driven management methods and automated processes to increase productivity and sustainability. SF allows farmers to more efficiently manage resources and to achieve higher quality and quantity crops. However, the relatively low adoption of SFT remains a concern in Portugal. This study shows that the age and education of farmers, the cost of investment in SFT, the trialability of SFT and the awareness of available information and training programs and of external financing are likely to impact the rate of adoption. By understanding these factors and their influence on the adoption of SFT, this study may provide assistance and guidance in addressing the low rate of adoption of SFT by policymakers and developers of SFT in Portugal.

9. Bibliography

Adesina, Akinwumi A., and Moses M. Zinnah. 1993. "Technology characteristics, farmers' perceptions and adoption decisions: A Tobit model application in Sierra Leone." *Agricultural Economics*, 9: 297–311. doi:10.1016/0169-5150(93)90019-9.

Adrian, Anne M., Shannon H. Norwood, and Paul L. Mask. 2005. "Producers' perceptions and attitudes toward precision agriculture technologies." *Computers and Electronics in Agriculture*, 48(3): 256–271. doi:10.1016/j.compag.2005.04.004.

Angrist, Joshua D. and Jörg-Steffen Pischke. 2009. *Mostly Harmless Econometrics: An Empiricist's Companion*. New Jersey: Princeton University Press.

Aubert, Benoit A., Andreas Schroeder, and Jonathan Grimaudo. 2012. "IT as enabler of sustainable farming: An empirical analysis of farmers' adoption decision of precision agriculture technology." *Decision Support Systems*, 54(1): 510–520. doi:10.1016/j.dss.2012.07.002.

Bacco, Manlio, Paolo Barsocchi, Erina Ferro, Alberto Gotta, and Massimiliano Ruggeri. 2019. "The Digitisation of Agriculture: A Survey of Research Activities on Smart Farming." *Array*, 3–4: 100009. doi:10.1016/j.array.2019.100009.

Balafoutis, Athanasios T., Bert Beck, Spyros Fountas, Zisis Tsiropoulos, Jürgen Vangeyte, Tamme van der Wal, I. Soto-Embodas, Manuel Gómez-Barbero, and Søren M. Pedersen. 2017. "Smart Farming Technologies – Description, Taxonomy and Economic Impact." In *Precision Agriculture: Technology and Economic Perspectives*, edited by S. M. Pedersen and K. M. Lind, 21–77. Cham: Springer International Publishing.

Baumgart-Getz, Adam, Linda S. Prokopy, and Kristin Floress. 2012. "Why farmers adopt best management practice in the United States: A meta-analysis of the adoption literature." *Journal of Environmental Management*, 96(1): 17–25. doi:10.1016/j.jenvman.2011.10.006.

Bursac, Zoran, C. H. Gauss, David K. Williams, and David W. Hosmer. 2008. "Purposeful selection of variables in logistic regression." *Source Code for Biology and Medicine*, 3 (1): 17. doi:10.1186/1751-0473-3-17.

Caffaro, Federica, and Eugenio Cavallo. 2019. "The Effects of Individual Variables, Farming System Characteristics and Perceived Barriers on Actual Use of Smart Farming Technologies: Evidence from the Piedmont Region, Northwestern Italy." *Agriculture*, 9(5): 111. doi:10.3390/agriculture9050111.

Calicioglu, Ozgul, Alessandro Flammini, Stefania Bracco, Lorenzo Bellù, and Ralph Sims. 2019. "The Future Challenges of Food and Agriculture: An Integrated Analysis of Trends and Solutions." *Sustainability*, 11: 222. doi:10.3390/su11010222.

Charania, Imran, and Xinrong Li. 2020. "Smart farming: Agriculture's shift from a labor intensive to technology native industry." *Internet of Things*, 9: 100142. doi:10.1016/j.iot.2019.100142.

Churchill Jr, Gilbert A. 1979. "A paradigm for developing better measures of marketing constructs." *Journal of Marketing Research*, 16(1): 64-73. doi:10.2307/3150876.

De Pinto, Alessandro, Nicola Cenacchi, Ho-Young Kwon, Jawoo Koo, and Shahnila Dunston. 2020. "Climate smart agriculture and global food-crop production." *PLOS ONE*, 15(4): e0231764. doi:10.1371/journal.pone.0231764.

Duflo, Esther, Michael Kremer, and Jonathan Robinson. 2008. "How High Are Rates of Return to Fertilizer? Evidence from Field Experiments in Kenya." *American Economic Review*, *98*(2): 482–488. doi:10.1257/aer.98.2.482.

Đurić, Ivan. 2020. *Digital technology and agricultural markets – Background paper for The State of Agricultural Commodity Markets (SOCO) 2020*. Rome: Food and Agriculture Organization of the United Nations.

European Commission. 2014. "What is Smart Farming? Smart-AKIS." Accessed May 20, 2021. https://www.smart-akis.com/index.php/network/what-is-smart-farming/.

European Commission. 2017a. *Shaping the digital (r)evolution in agriculture.* EIP-AGRI Service Point Publication. https://ec.europa.eu/eip/agriculture/sites/default/files/eip-agri_brochure_digital_revolution_2018_en_web.pdf.

European Commission. 2017b. *Smart Farming Thematic Network.* EIP-AGRI Service Point Publication. https://ec.europa.eu/eip/agriculture/sites/default/files/field_core_attachments/nw_smartakis_10012017_en.pdf.

European Commission. 2019a. *Agriculture Research Factsheet: Digital Transformation in Agriculture and Rural Areas*. https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/farming/documents/factsheet-agri-digital-transformation_en.pdf.

European Commission. *2019b. Analytical factsheet for Portugal: Nine objectives for a future Common Agricultural Policy.* https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/by_country/documents/analytical_factsheet_pt.pdf.

European Commission. 2020a. *Statistical Factsheet Portugal.* https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/farming/documents/agri-statistical-factsheet-pt_en.pdf.

European Commission. 2020b. *Factsheet on 2014-2020 Rural Development Programme for Portugal Continent*. https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/key_policies/documents/rdp-factsheet-portugal-continente_en.pdf.

Edwards-Jones, G. 2006. "Modelling farmer decision-making: Concepts, progress and challenges." *Animal Science*, 82(6): 783–790. doi:10.1017/ASC2006112.

FAO. 2018. *Future of Food and Agriculture 2018: Alternative pathways to 2050.* Rome: Food and Agriculture Organization of the United Nations.

FAO. 2020. *The State of Agricultural Commodity Markets 2020*. *Agricultural markets and sustainable development: Global value chains, smallholder farmers and digital innovation.* Rome: Food and Agriculture Organization of the United Nations.

Feder, Gershon, Richard E. Just, and David Zilberman. 1985. "Adoption of Agricultural Innovations in Developing Countries: A Survey." *Economic Development and Cultural Change*, 33(2): 255–298. doi:10.1086/451461.

Field, Andy. 2018. *Discovering Statistics Using IBM SPSS Statistics (5th ed.).* Los Angeles: SAGE Publications.

Foster, Andrew D., and Mark R. Rosenzweig. 2010. "Microeconomics of Technology Adoption." *Annual Review of Economics*, 2(1): 395–424. doi:10.1146/annurev.economics.102308.124433.

Fountas, S., S. Blackmore, D. Ess, S. Hawkins, G. Blumhoff, J. Lowenberg-Deboer, C.G. Sorensen. 2005. "Farmer Experience with Precision Agriculture in Denmark and the US Eastern Corn Belt." *Precision Agric*, 6: 121–141. doi: 10.1007/s11119-004-1030-z

Heckman, J.J. 2010. Selection Bias and Self-Selection. In Microeconometrics, edited by S.N. Durlauf and L.E. Blume, 242–266. London: Palgrave Macmillan.

Instituto National de Estatistìca. 2019. *Estatísticas Agrícolas – 2018*. *Lisbon: INE.*

Instituto Nacional de Estatística. 2021. *Recenseamento Agrícola 2019*. *Lisbon: INE.*

Jakku, Emma, Bruce Taylor , Aysha Fleming, Claire Mason, Simon Fielke, Chris Sounness, and Peter Thorburn. 2019. "“If they don’t tell us what they do with it, why would we trust them?” Trust, transparency and benefit-sharing in Smart Farming." *NJAS - Wageningen Journal of Life Sciences*, 90–91: 100285. doi:10.1016/j.njas.2018.11.002.

Jouanjean, Marie-Agnes, Francesca Casalini, Leanne Wiseman, and Emily Gray. 2020. "Issues around data governance in the digital transformation of agriculture: The farmers’ perspective." *OECD Food, Agriculture and Fisheries Papers*, 146: 1–39.

JRC, Pablo J. Zarco-Tejada, Neil Hubbard and Philippe Loudjani. 2014. *Precision agriculture: An opportunity for EU farmers: Potential support with the CAP 2014-2020.* Luxembourg: Office for Official Publications of the European Communities.

Kernecker, Marie, Andrea Knierim, Angelika Wurbs, Teresa Kraus and Friederike Borges. 2020. "Experience versus expectation: farmers’ perceptions of smart farming technologies for cropping systems across Europe." *Precision Agriculture*, 21: 34–50. doi:10.1007/s11119-019-09651-z.

Loures, Luís, Alejandro Chamizo, Paulo Ferreira, Ana Loures, Rui Castanho, and Thomas Panagopoulos. 2020. "Assessing the Effectiveness of Precision Agriculture Management Systems in Mediterranean Small Farms." *Sustainability*, *12*(9): 3765. doi:10.3390/su12093765.

McBride, William D., and Stan G. Daberkow. 2003. "Information and the Adoption of Precision Farming Technologies." *Journal of Agribusiness*, 21(1): 21–38. doi:10.22004/ag.econ.14671.

Morton, John F. 2007. "The impact of climate change on smallholder and subsistence agriculture." *Proceedings of the National Academy of Sciences*, 104(50): 19680–19685. doi:10.1073/pnas.0701855104.

Moser, Christine M., and Christopher B. Barrett. 2003. "The Complex Dynamics of Smallholder Technology Adoption: The Case of SRI in Madagascar." *Agriculture Economics*, 35(3): 373–388. doi:10.1111/j.1574-0862.2006.00169.x.

Mulla, David J. 2013. "Twenty five years of remote sensing in precision agriculture: Key advances and remaining knowledge gaps." *Biosystems Engineering*, 114(4): 358–371. doi:10.1016/j.biosystemseng.2012.08.009.

Nelson, Gerald C., Mark W. Rosegrant, Amanda Palazzo, Ian Gray, Christina Ingersoll, Richard Robertson, Simla Tokgoz, Tingju Zhu, Timothy B. Sulser, Claudia Ringler, Siwa Msangi, and Liangzhi You. 2010. *Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options*. Washington, DC: International Food Policy Research Institute.

Nelson, Richard R., and Edmund S. Phelps. 1966. "Investment in Humans, Technological Diffusion, and Economic Growth." *American Economic Review,* 56(1/2): 69–75. doi:10.1016/B978-0-12-554002-5.50015-7.

Nunes, Leonel J. R., Catarina I. R. Meireles, Carlos J. Pinto Gomes, and Nuno M. C. Almeida Ribeiro. 2019. "The Evolution of Climate Changes in Portugal: Determination of Trend Series and Its Impact on Forest Development." *Climate, 7*(6): 78. doi:10.3390/cli7060078.

Nunnally, J. C. 1978. An Overview of Psychological Measurement. In *Clinical Diagnosis and Mental Disorders*, edited by Benjamin B. Wolman, 97–146. Boston, MA: Springer.

Paxton, Kenneth W., Sachin Chintawar, Roland K. Roberts, Dayton M. Lambert, Sherry L. Larkin, Steven W. Martin, Ashok K. Mishra, and James A. Larson. 2011. "Precision Agriculture Technology Adoption for Cotton Production." *Southern Agricultural Economics Association Annual Meeting.* doi:10.22004/ag.econ.56486.

Pituch, Keenan A., and James Stevens. 2016. *Applied multivariate statistics for the social sciences: Analyses with SAS and IBM's SPSS (6th ed.).* New York: Routledge.

Pivoto, Dieisson, Paulo Dabdab Waquil, and Edson Talamini. 2018. "Scientific development of smart farming technologies and their application in Brazil." *Information Processing in Agriculture*, 5: 21–32. doi:10.1016/j.inpa.2017.12.002.

Reichardt, M., C. Jürgens, U. Klöble, J. Hüter, and K. Moser. 2009. "Dissemination of precision farming in Germany: Acceptance, adoption, obstacles, knowledge transfer and training activities." *Precision Agriculture*, 10: 525–545. doi:10.1007/s11119-009-9112-6.

Rogers, E. M. (1962). *Diffusion of innovations (3rd ed.).* New York: The Free Press; Collier Macmillan.

Rosegrant, Mark W., Jawoo Koo, Nicola Cenacchi, Claudia Ringler, Richard Robertson, Myles Fisher, Cindy Cox, Karen Garrett, Nicostrato D. Perez, and Pascale Sabbagh. 2014. *Food Security in a World of Natural Resource Scarcity—The Role of Agricultural Technologies*. Washington, DC: International Food Policy Research Institute. doi:10.2499/9780896298477.

Schimmelpfennig, David. 2016. "Farm Profits and Adoption of Precision Agriculture." ERR-217, U.S. Department of Agriculture, *Economic Research Service*.

Skelly, Andrea, Joseph Dettori, and Erika Brodt. 2012. "Assessing bias: The importance of considering confounding." *Evidence-Based Spine-Care Journal*, 3(1): 9–12. doi:10.1055/s-0031-1298595.

Smith, Gary. 2015a. "10—Multiple Regression." In *Essential Statistics, Regression, and Econometrics (2nd ed.),* edited by Gary Smith, 301–337. Academic Press.

Smith, Gary. 2015b. "5—Sampling." In *Essential Statistics, Regression, and Econometrics (2nd ed),* edited by Gary Smith, 139–161. Academic Press.

Szumilas, Magdalena. 2010. "Explaining odds ratios." *Journal of the Canadian Academy of Child and Adolescent Psychiatry*, 19(3): 227–229.

United Nations. 2019. *Global Sustainable Report 2019: The Future is Now – Science for Achieving Sustainable Development*. New York: United Nations.

Walter, Achim, Robert Finger, Robert Huber, and Nina Buchmann. 2017. "Opinion: Smart farming is key to developing sustainable agriculture." *Proceedings of the National Academy of Sciences of the United States of America*, 114(24): 6148–6150. doi:10.1073/pnas.1707462114.

Wolfert, Sjaak, Lan Ge, Cor Verdouw, and Marc-Jeroen Bogaardt. 2017. "Big Data in Smart Farming – A review." *Agricultural Systems*, 153: 69–8. doi:10.1016/j.agsy.2017.01.023.

World Bank. 2019. *"Agriculture, forestry, and fishing, value added (% of GDP) - Portugal*." The World Bank Group. Accessed May 20, 2021. https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=PT

World Bank. 2019. *"Employment in agriculture (% of total employment) (modeled ILO estimate) - Portugal."* The World Bank Group. Accessed May 20, 2021. https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=PT

Zagata, L., J. Hrabák, M. Lošťák, M. Bavorová, T. Ratinger, L.-A. Sutherland, an A. McKee. 2017. *Research for AGRI Committee – Young farmers – Policy implementation after the 2013 CAP reform*. Luxembourg: Office for Official Publications of the European Communities.

10. Appendixes

Appendix A. Explanation and measurement of variables in the study

Variable	Variable Type	Measurement / Coded
Outcome Variable		
Adoption of SFT	Binary	1 when farmer adopted SFT, 0 otherwise
Predictor Variables		
Age	Ordinal	1 = Below 35 years, 2 = between 35-54 years, 3 = between 55-64 years, 4 = 65 years or above
Education level	Ordinal	1 = Primary school, 2 = Secondary school, 3 = Higher education
Farm size	Ordinal	1 = Less than 5 ha, 2 = 5-25, 3 = 26-50, 4 = 51-100, 5 = 101-500, 6 = 501-1000, 7 = above 1000 ha
Farm income	Ordinal	1 = Less than €10.000, 2 = €10.001-25.000, 3 = €25.001-50.000, 4 = €50.001-75.000, 5 = €75.001-100.000, 6 = more than €100.000
Cost of investment	Ordinal	1 = Strongly agree, 2 = Agree, 3 = Neutral, 4 = Disagree, 5 = Strongly disagree
Benefits	Ordinal	1 = Strongly agree, 2 = Agree, 3 = Neutral, 4 = Disagree, 5 = Strongly disagree
Ease of utilization	Ordinal	1 = Strongly agree, 2 = Agree, 3 = Neutral, 4 = Disagree, 5 = Strongly disagree
Compatibility	Ordinal	1 = Strongly agree, 2 = Agree, 3 = Neutral, 4 = Disagree, 5 = Strongly disagree
Trialability	Ordinal	1 = Strongly agree, 2 = Agree, 3 = Neutral, 4 = Disagree, 5 = Strongly disagree
Stable broadband access	Binary	1 when available to the farmer, 0 otherwise
Awareness of available external financing	Binary	1 when farmer is aware, 0 otherwise
Awareness of available information and training programs	Binary	1 when farmer is aware, 0 otherwise

Appendix B. Farmer survey: "State of Smart Farming in Portugal"

Welcome to My Survey

Dear Participant

This survey intends to collect information for a master's thesis at NOVA School of Business and Economics.

It is intended to Entrepreneurs of the Agricultural Sector acting in Portugal and aims to analyze the current state of the Smart Farming Technologies (SFT) in Portugal.

I would appreciate it if you took a few moments to complete the online questionnaire. There are no right or wrong answers, and it is your candid views that count for the survey. Your responses are strictly confidential. The final results of the research are completely anonymous and can in no way be traced to individual responses.

Thank you in advance for your contribution. Your time and effort are greatly valued!

For more information, please contact martin.buhl@novasbe.pt.

Filter Questions

1. Is cultivation of field crop (as opposed to livestock farming) the main activity of this farm?

Yes (continue)	☐	No (stop survey)	☐

Part 1: Farmer's demographics and farm structure

Let's start with some questions about you and your farm.

1. What type of crop are you cultivating?

2. In which region is your farm located?

3. Which of the following types describe your farm best?

More than one generation family farm	☐
First generation family farm	☐
Part of a farming company or cooperative	☐

4. How many hectares of land are cultivated on this farm?

Less than 5 ha	
Between 5 and 25 ha	
Between 26 and 50 ha	
Between 51 and 100 ha	
Between 101 and 500 ha	
Between 501 and 1000 ha	
More than 1000 ha	

5. What is the farm's average operating profit for the last 5 years?

Less than €10,000	
Between €10,001 and €25,000	
Between €25,001 and €50,000	
Between €50,001 and €75,000	
Between €75,001 and €100,000	
More than €100,000	

6. What is your age group?

Below 35 years	
Between 35-50	
Between 51-65	
Above 65 years	

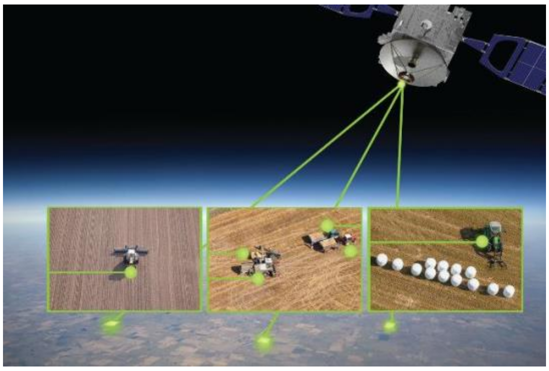
7. What is the highest education that you have completed?

Primary school	
Secondary school	
Higher education	

Part 2: Farming Technology

Now let's turn to your perception of Smart Farming Technologies (SFT).

1. Are you aware of any of the following SFT? (multiple answers are possible)

Soil Monitoring Sensors 	
Yield Monitoring 	
Satellite Technology 	
Drones 	

Robotic Farming Machines 	
Variable Rate Technology 	
Farm Management Systems 	
Data Analytics Systems 	
None of the above	

2. How did you learn about SFT?

Industry representative	
Agricultural consultants	
Other farmers	
Friends and families	
Government and local authorities	
Farmer's association	
NGOs	
Tradeshows	
Demonstration workshop	
Internet	
News media	
None of the above	

Please indicate the extent to which you agree with the following statements (Strongly agree, Agree, Neither agree nor disagree, Disagree, Strongly disagree):

3. Cost of investment
   a. SFT are very costly to acquire.
   b. The cost of maintenance of SFT are very high.
   c. The cost of training of employees to use SFT are very high.

4. Benefits
   a. Using SFT increases productivity (increase output and/or increased quality) at my farm.
   b. Using SFT reduces input costs (water, fertilizer, fuel, labor, etc.) at my farm.
   c. Using SFT provides me better information for decision-making.

5. Compatibility
   a. Using SFT fits well with the way I like to work.
   b. SFT are compatible with the existing equipment and infrastructure of my farm.
   c. SFT are compatible with the operations processes at my farm.

6. Ease of Utilization
   a. I find SFT easy to use.
   b. Learning to operate SFT is easy for me and my employees.
   c. Using SFT makes it easier to perform my job.

7. Trialability
   a. I would be able to use SFT on a trial basis.
   b. I would be able to test SFT properly.
   c. I would be permitted to use SFT long enough to test their benefits.

8. Please specify if you have adopted any of the following SFT? (multiple answers are possible)

Soil Monitoring Sensors	☐
Yield Monitoring	☐
Satellite Technology	☐
Drones	☐
Robotic Farming Machines	☐
Variable Rate Technology	☐
Farm Management Systems	☐
Data Analytics Systems	☐
None of the above	☐

Part 3: Supporting institutions

Now let's turn to supporting institutions for the adoption of SFT.

1. Do you have stable broadband connection at your farm?

Yes	☐	No	☐

2. Are you aware of any external financial assistance from any source (subsidies, Credit, Grants, Tax advantages) related to SFT available?

Yes	☐	No	☐

3. Are you aware of any information events or training programs related to SFT?

Yes	☐	No	☐

This is the end of the survey — Thank you very much for your cooperation in this study!

Appendix C. The logistic regression equation

A logistic regression model allows us to establish a relationship between a binary outcome variable and a set of predictor variables. It models the logit-transformed probability (log odds) as a linear relationship with the predictor variables. Let **Y** be the binary outcome variable indicating failure/success with {0,1} and p be the predicted probability of **Y** to be 1, p = P(Y=1). Let $x_1, \ldots, x_k$ be a set of predictor variables. Then the logistic regression of **Y** on $x_1, \ldots, x_k$ estimates coefficient values for $\beta_0, \beta_1, \ldots, \beta_k$ through maximum likelihood method, resulting in the following equation:

$$\log\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k$$

where, $\beta_0 = constant$

$\beta_1 \rightarrow \beta_k = regression\ coefficient\ for\ k\ predictor\ variables\ x_1 \rightarrow x_k$

$p = probability\ of\ event\ occuring\ e.g. person\ adoption\ SFT$

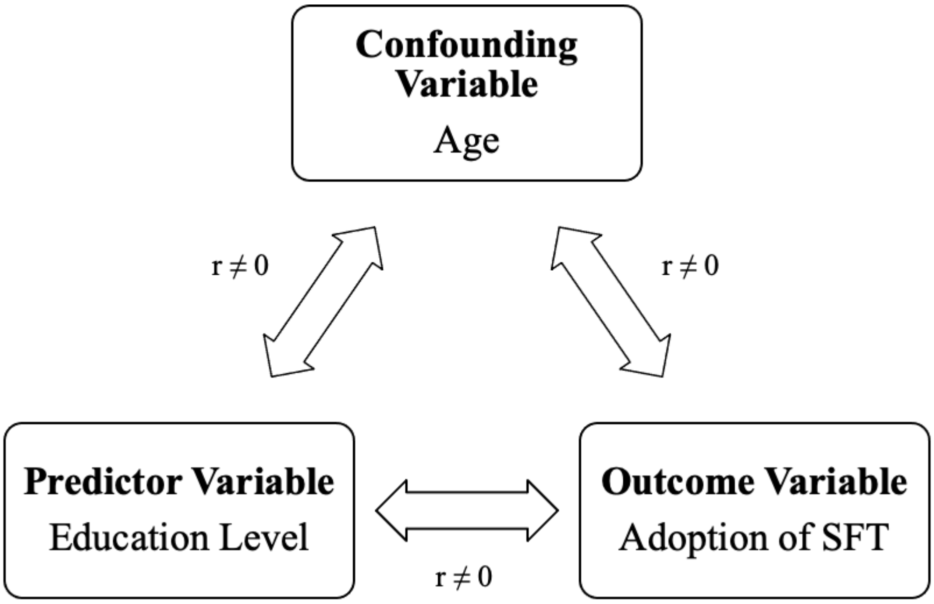
$\frac{p}{1-p} = odds\ ratio$

The equation provides a model which can be used to predict the log odds of an event happening for a particular individual given a set of predictor variables. For instance, the regression coefficient β tells the amount of increase (or decrease, if the sign of the coefficient is negative) in the predicted log odds of adoption that would be predicted by a one-unit increase (or decrease) in the predictor, holding all other predictor variables constant.

Appendix D. Likert scale Items and Cronbach alpha

Indicators	Construct Relability (CR >= 0.7)
Cost of Investment	.702
1. SFT are very costly to acquire.	
2. The cost of maintenance of SFT are very high.	
3. The cost of training of employees to use SFT are very high.	
Relative Benefits	.796
1. Using SFT increases productivity (increase output and/or increased quality) at my farm.	
2. Using SFT reduces input costs (water, fertilizer, fuel, labor, etc.) at my farm.	
3. Using SFT provides me better information for decision-making.	
Compatibility	.833
1. Using SFT fits well with the way I like to work.	
2. SFT are compatible with the existing equipment and infrastructure of my farm.	
3. SFT are compatible with the operations processes at my farm.	
Ease of Utilization	.746
1. I find SFT easy to use.	
2. Using SFT makes it easier to perform my job.	
3. Learning to operate SFT is easy for me and my employees.	
Trialability	.953
1. I would be able to use SFT on a trial basis.	
2. I would be able to test SFT properly.	
3. I would be permitted to use SFT long enough to test their benefits.	

Appendix E. Example of omitted variable bias and confounding variable



Note: r stands for correlation coefficient

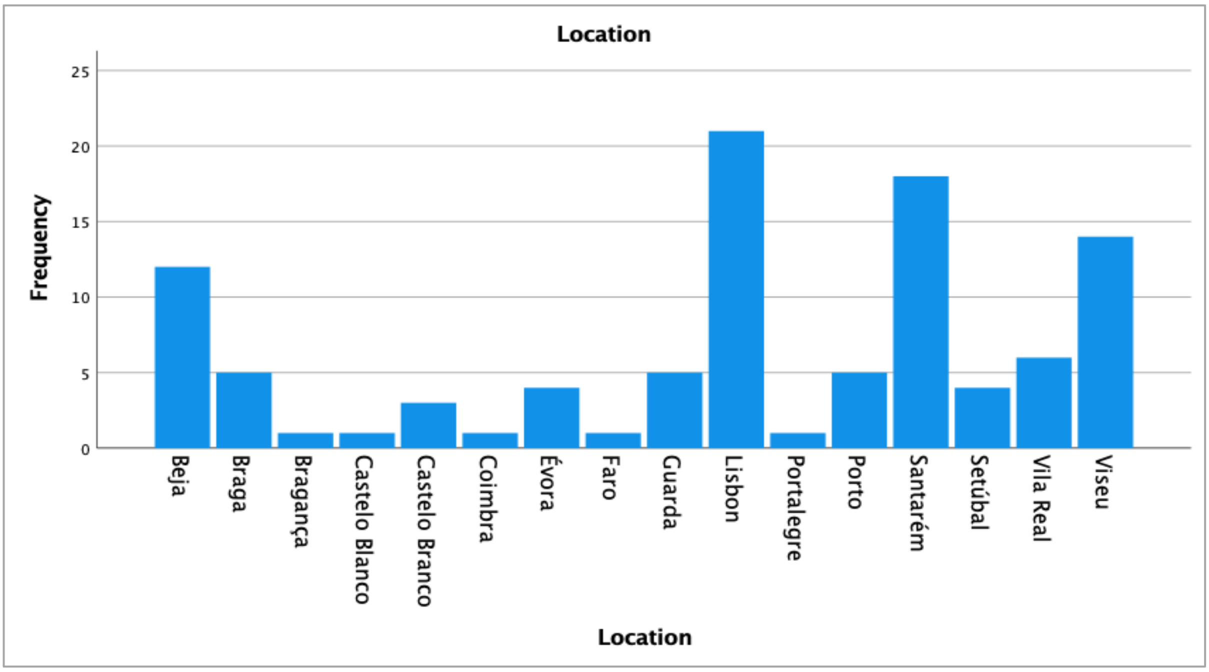
Appendix F. Descriptive findings and frequencies of the study

Crop types

	Frequency	Percent
Amendoal	3	2.4
Arroz	1	0.8
Aveia	2	1.6
Azevém	1	0.8
Baga de sabugueiro	1	0.8
Batata	2	1.6
Batata-doce	1	0.8
Cereais	2	1.6
Cerejas	1	0.8
Cevada	3	2.4
Citrinos	1	0.8
Colza	1	0.8
Ervilha	2	1.6
Eucaliptos	1	0.8
Floresta	1	0.8
Frutos	1	0.8
Girassol	2	1.6
Horticultura	4	3.2
Luzerna	1	0.8
Milho	17	13.6
Mirtilo	2	1.6
Nogueiras	1	0.8
Olival	12	9.6
Pereiras	1	0.8
Plantas aromáticas	1	0.8
Plantas ornamentais	1	0.8
Sobreiros	1	0.8
Sorgo	2	1.6
Tomate	1	0.8
Trigo	7	5.6
Vegetais	1	0.8
Vinha	47	37.6
Total	125	100.0

Location

	Frequency	Percent
Beja	12	11.8
Braga	5	4.9
Bragança	1	1.0
Castelo Blanco	1	1.0
Castelo Branco	3	2.9
Coimbra	1	1.0
Évora	4	3.9
Faro	1	1.0
Guarda	5	4.9
Lisbon	21	20.6
Portalegre	1	1.0
Porto	5	4.9
Santarém	18	17.6
Setúbal	4	3.9
Vila Real	6	5.9
Viseu	14	13.7
Total	102	100.0



SFT Awareness

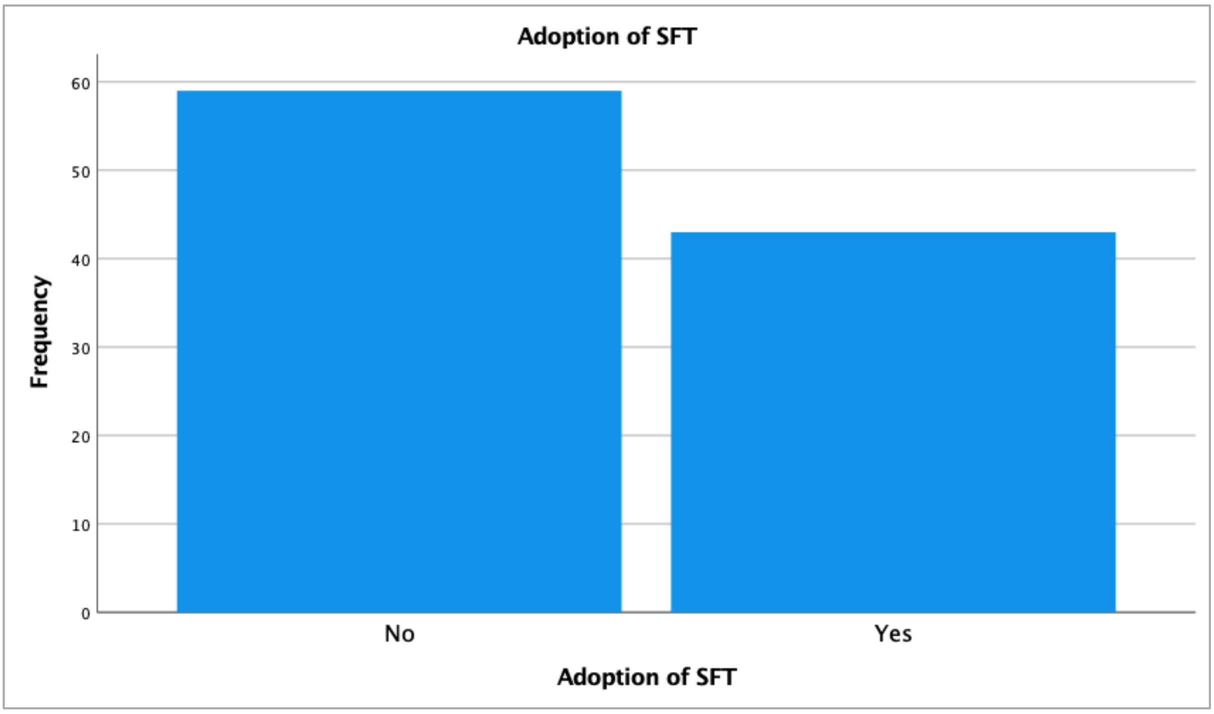
	Frequency	Percent
Soil monitoring sensors	76	16.0
Yield monitoring	63	13.3
Satellite technology	55	11.6
Drones	53	11.2
Robotic farming machines	59	12.5
Variable rate technology	46	9.7
Farm management system	69	14.6
Data analytics systems	48	10.1
None	5	1.1
Total	474	100.0

Sources of Information

	Frequency	Percent
Industry representative	35	8.1
Agricultural consultants	49	11.3
Other farmers	48	11.1
Friends and families	28	6.5
Government and local authorities	12	2.8
Farmer's association	46	10.7
Non-Governmental Organisation	20	4.7
Tradeshows	56	13
Demonstrations workshops	38	8.8
Internet	58	13.4
News media	36	8.3
None	6	1.4
Total	432	100.0

Adoption of SFT

	Frequency	Percent
No	59	57.8
Yes	43	42.2
Total	102	100.0

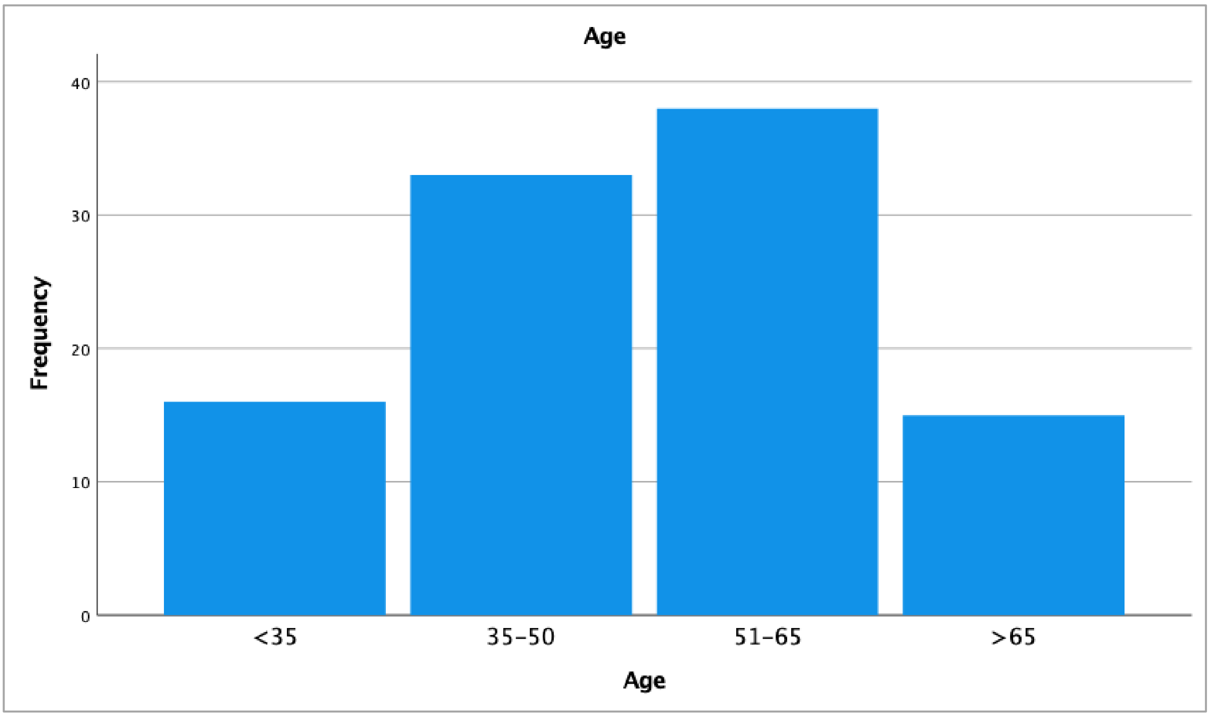


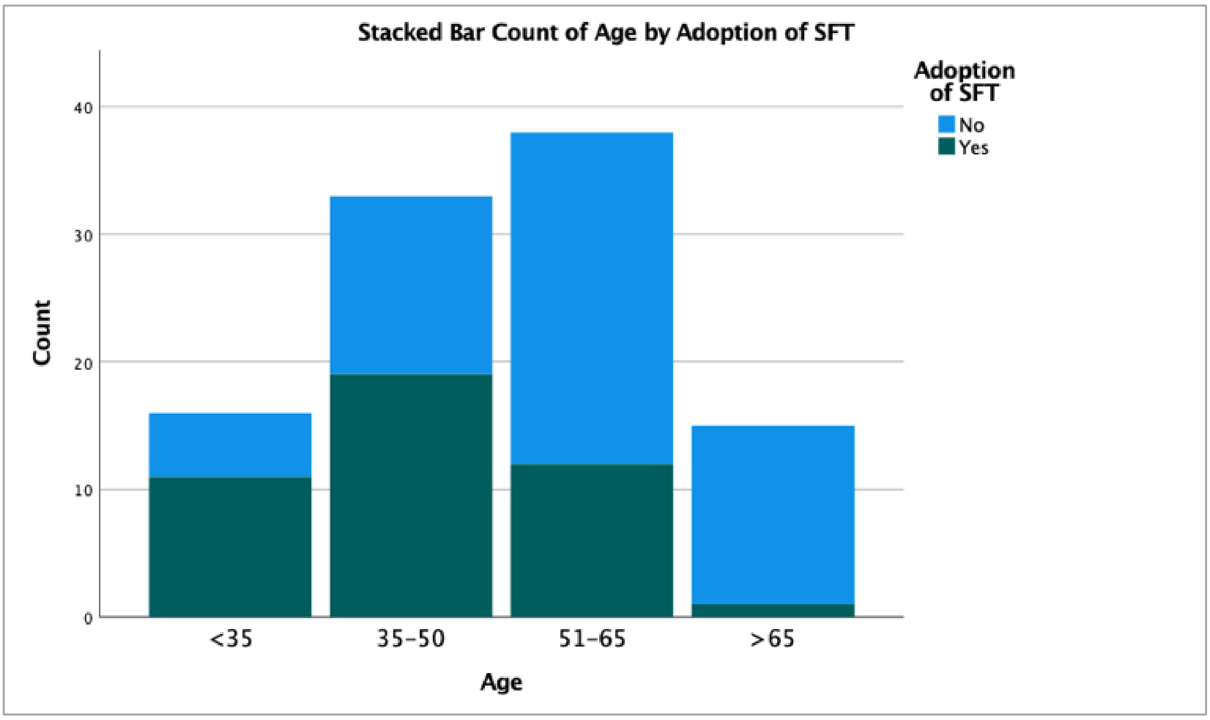
Adoption by type of SFT

	Frequency	Percent
Soil monitoring sensors	35	18.0
Yield monitoring	32	16.5
Satellite technology	25	12.9
Drones	21	10.8
Robotic farming machines	16	8.2
Variable rate technology	15	7.7
Farm management system	31	16.0
Data analytics systems	19	9.8
Total	194	100.0

Age

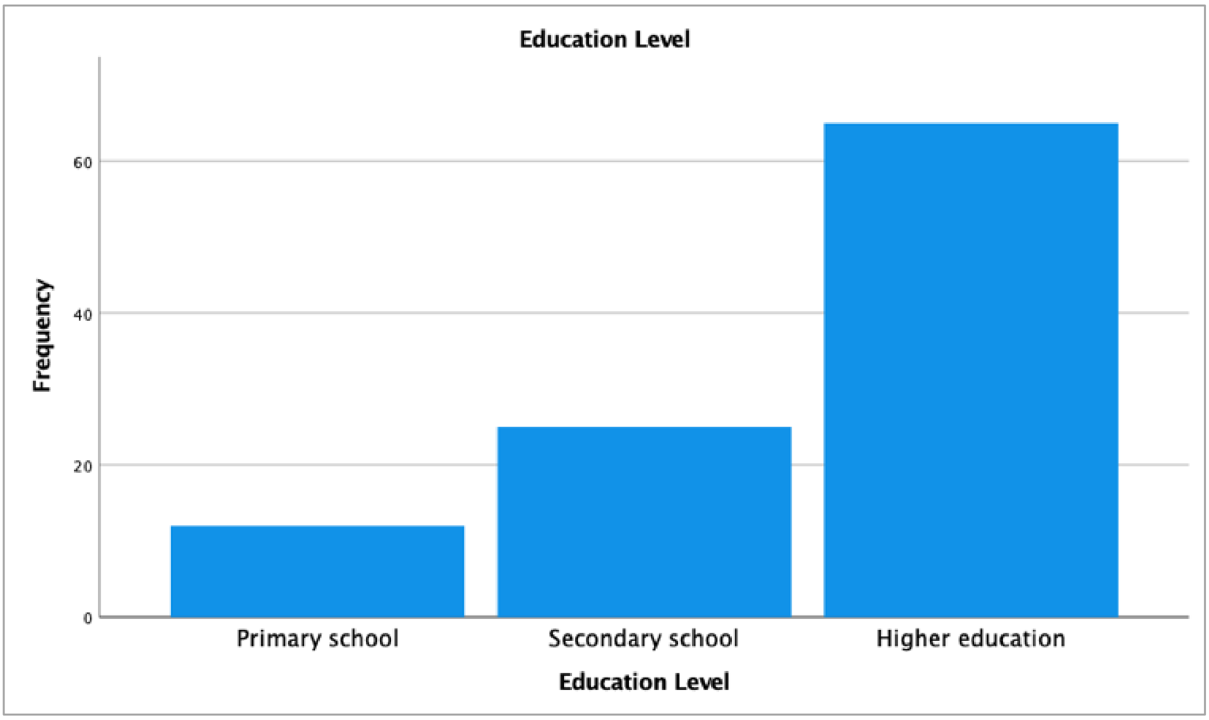
	Frequency	Percent
<35	16	15.7
35-50	33	32.4
51-65	38	37.3
>65	15	14.7
Total	102	100.0

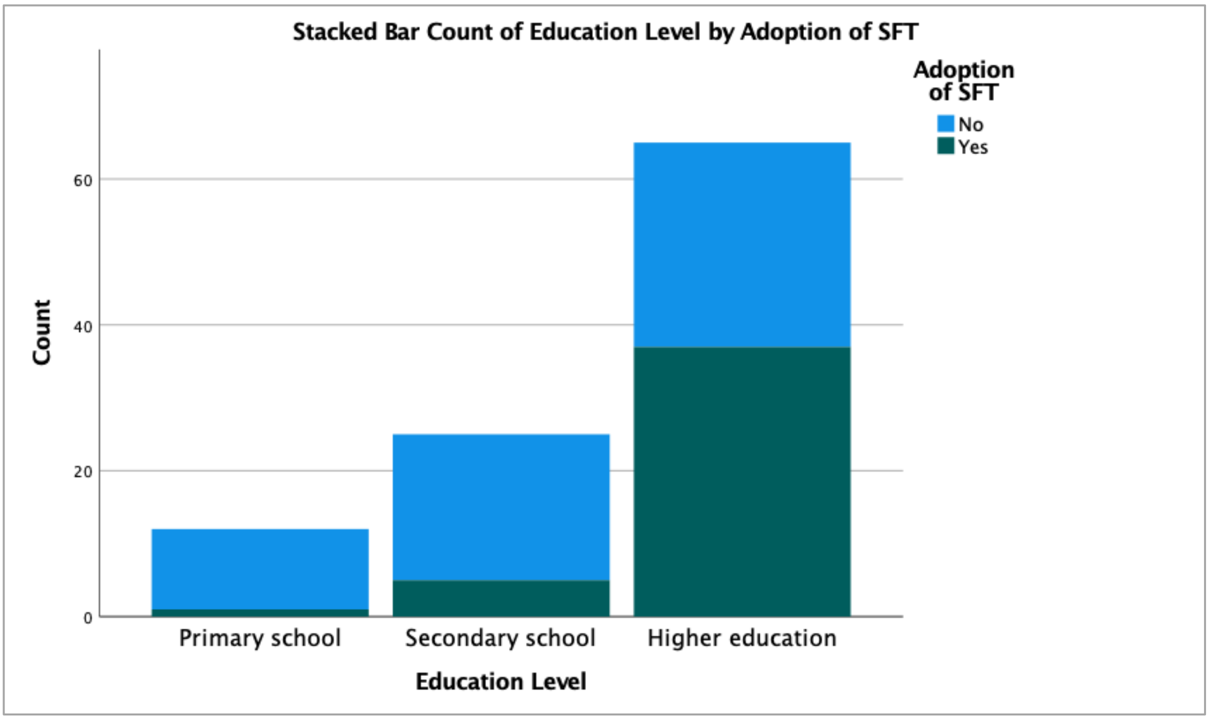




Education Level

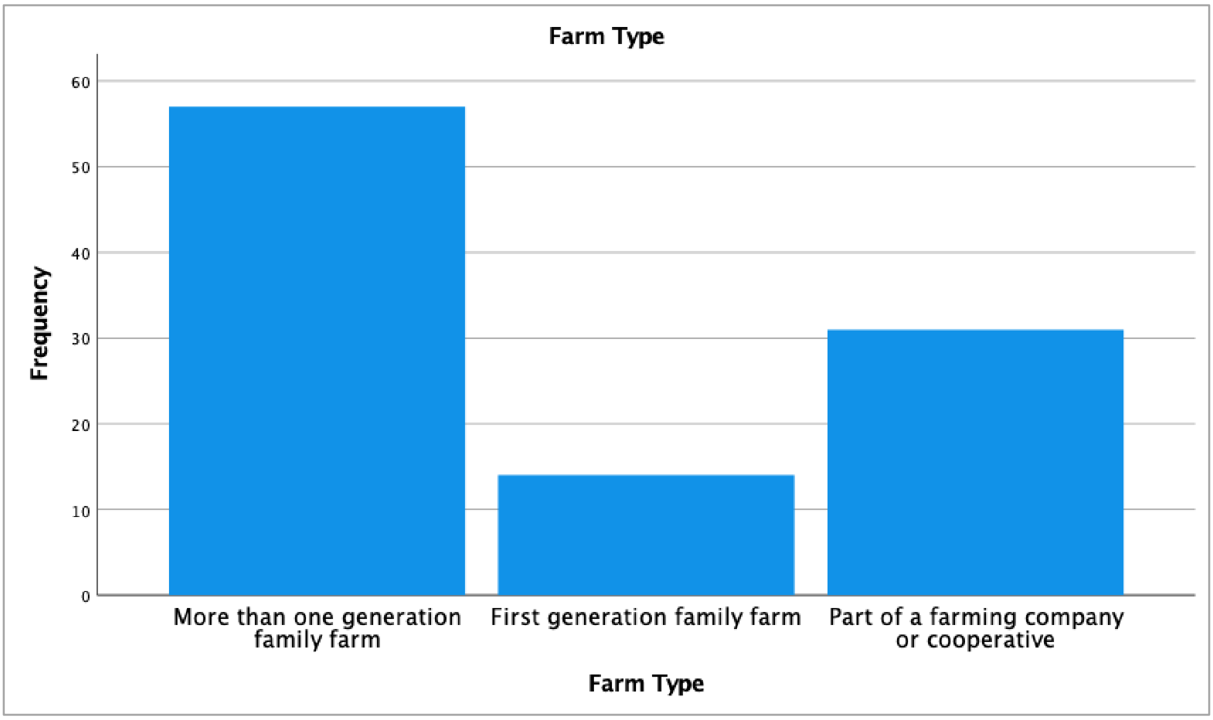
	Frequency	Percent
Primary school	12	11.8
Secondary school	25	24.5
Higher education	65	63.7
Total	102	100.0

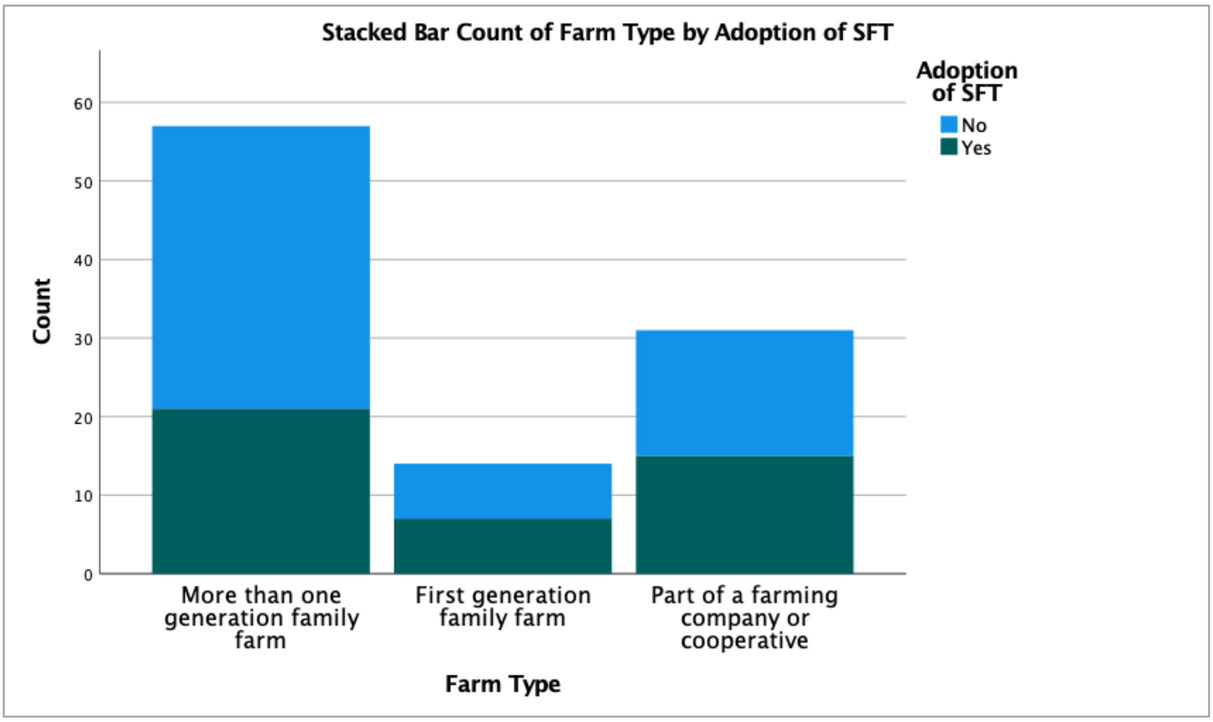




Farm Type

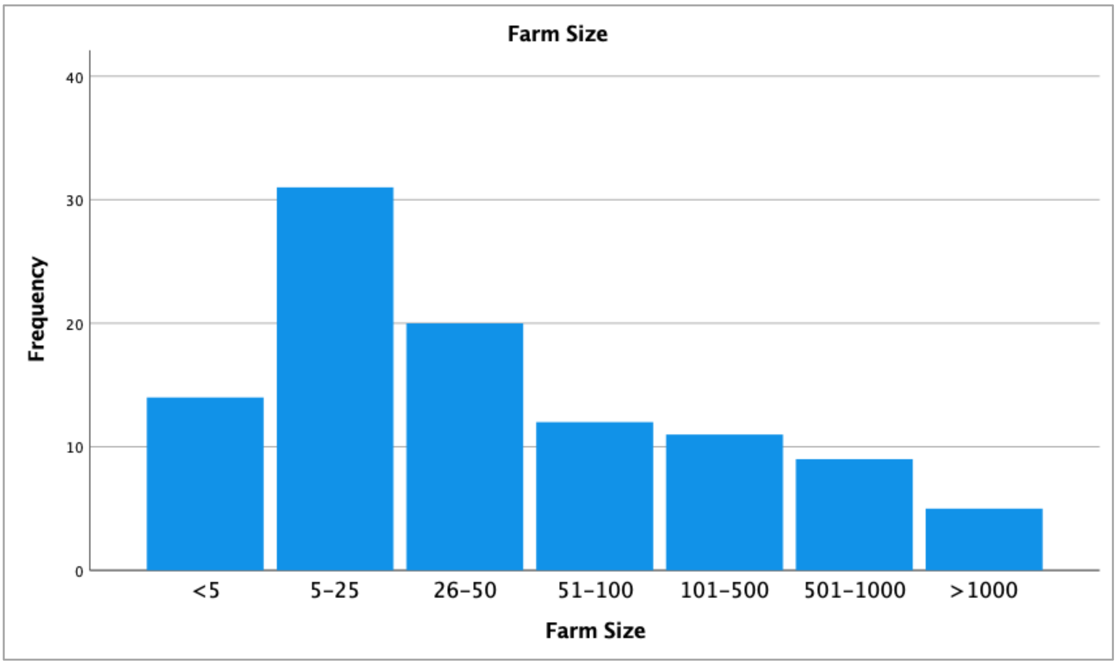
	Frequency	Percent
More than one generation family farm	57	55.9
First generation family farm	14	13.7
Part of a farming company or cooperative	31	30.4
Total	102	100.0

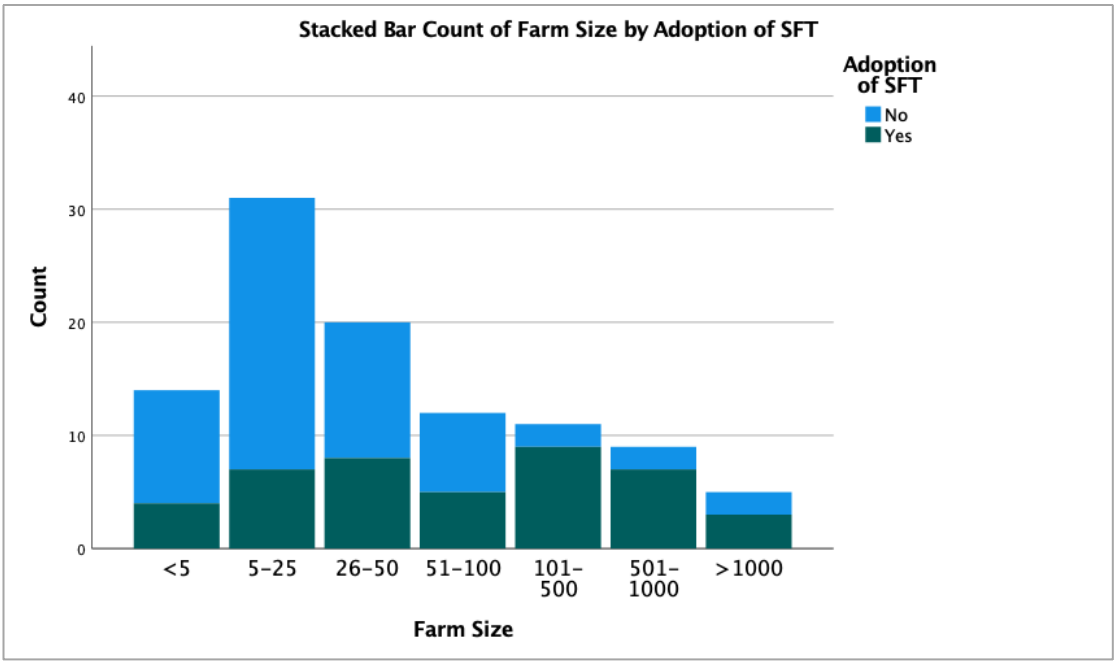




Farm Size

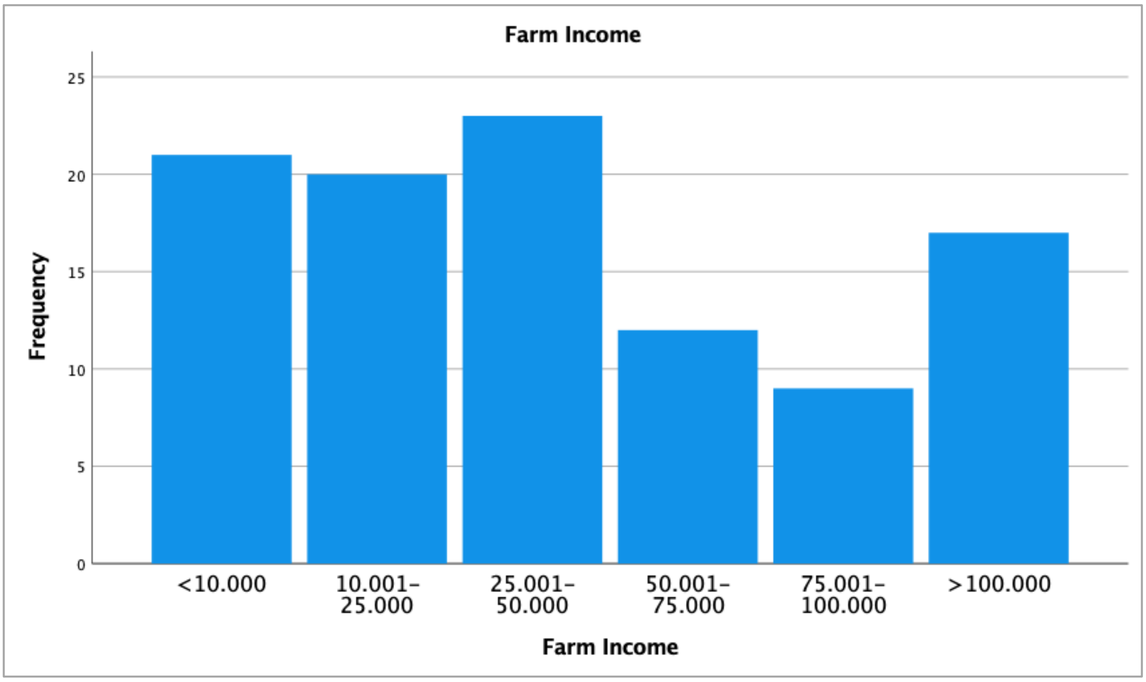
	Frequency	Percent
<5	14	13.7
5-25	31	30.4
26-50	20	19.6
51-100	12	11.8
101-500	11	10.8
501-1000	9	8.8
>1000	5	4.9
Total	102	100.0

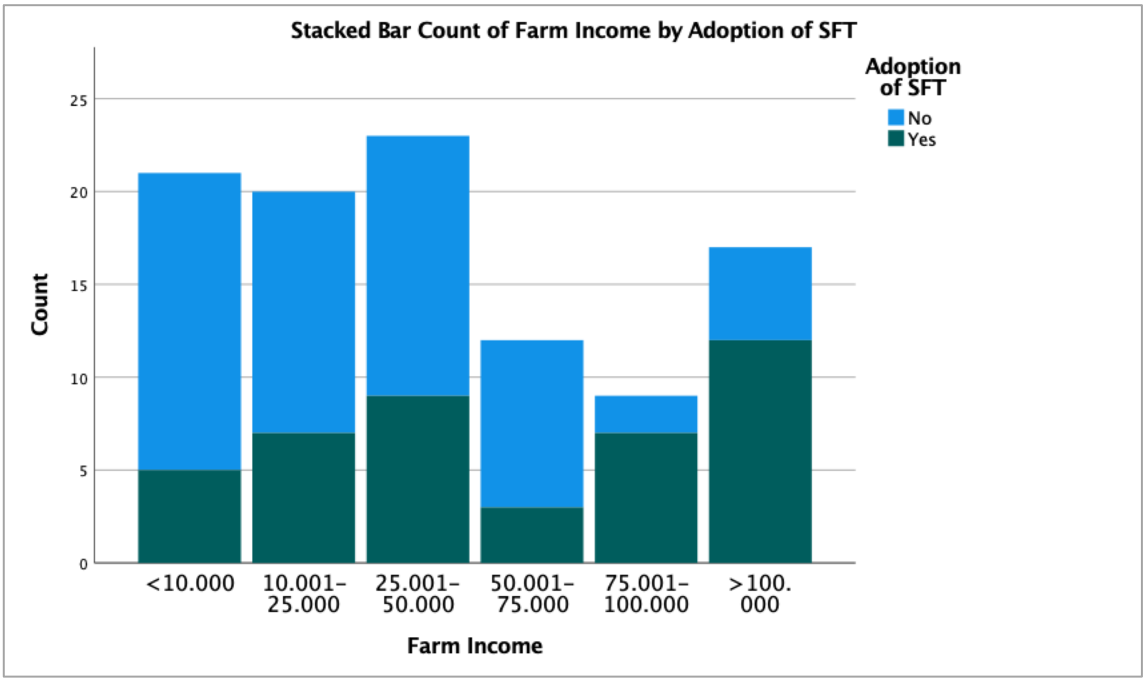




Farm Income

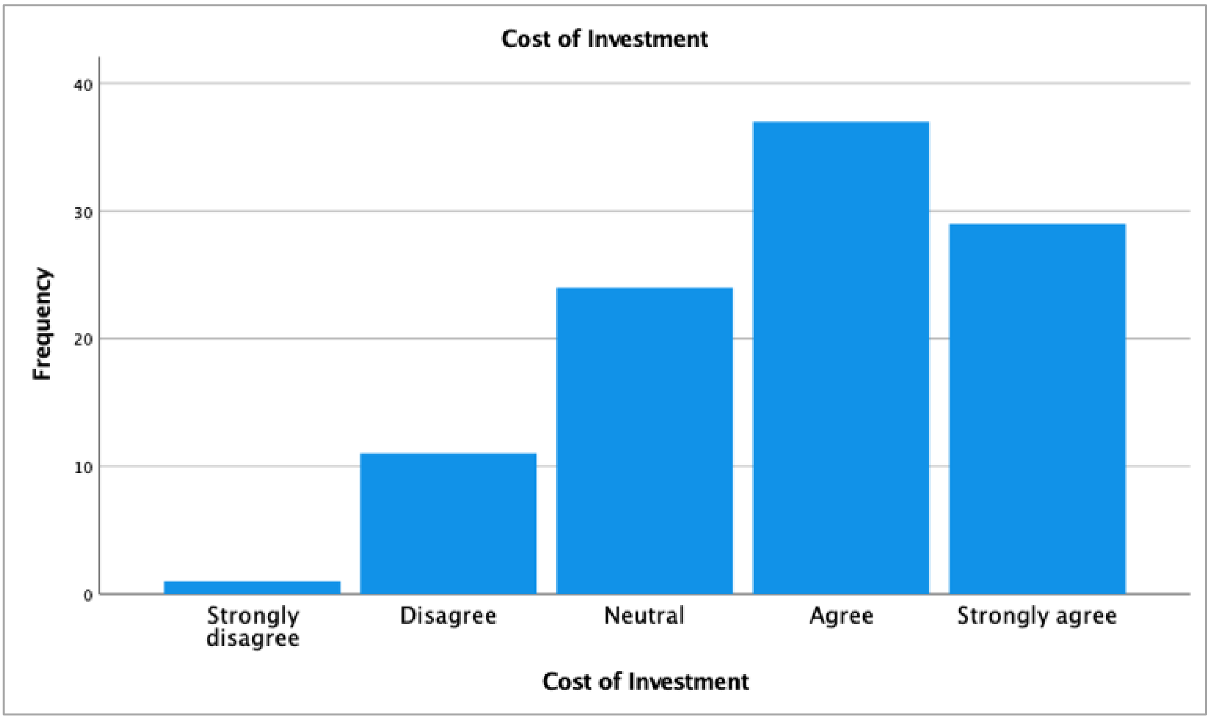
	Frequency	Percent
<10.000	21	20.6
10.001-25.000	20	19.6
25.001-50.000	23	22.5
50.001-75.000	12	11.8
75.001-100.000	9	8.8
>100.000	17	16.7
Total	102	100.0

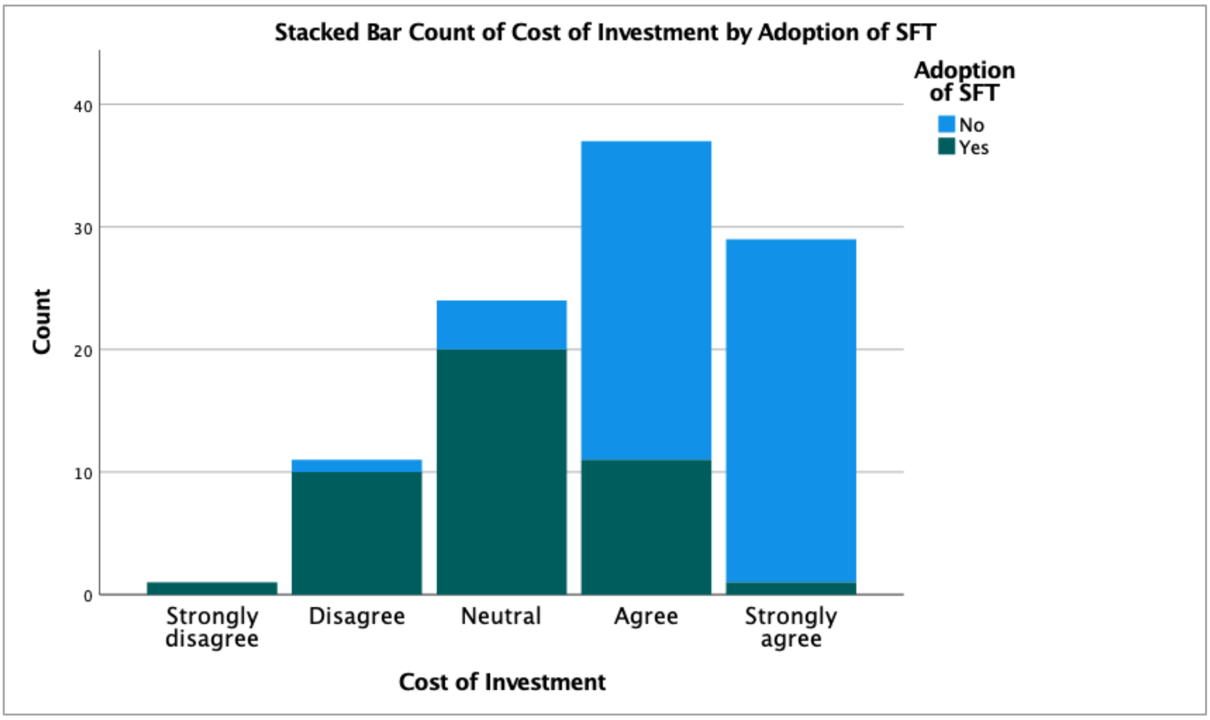




Cost of Investment

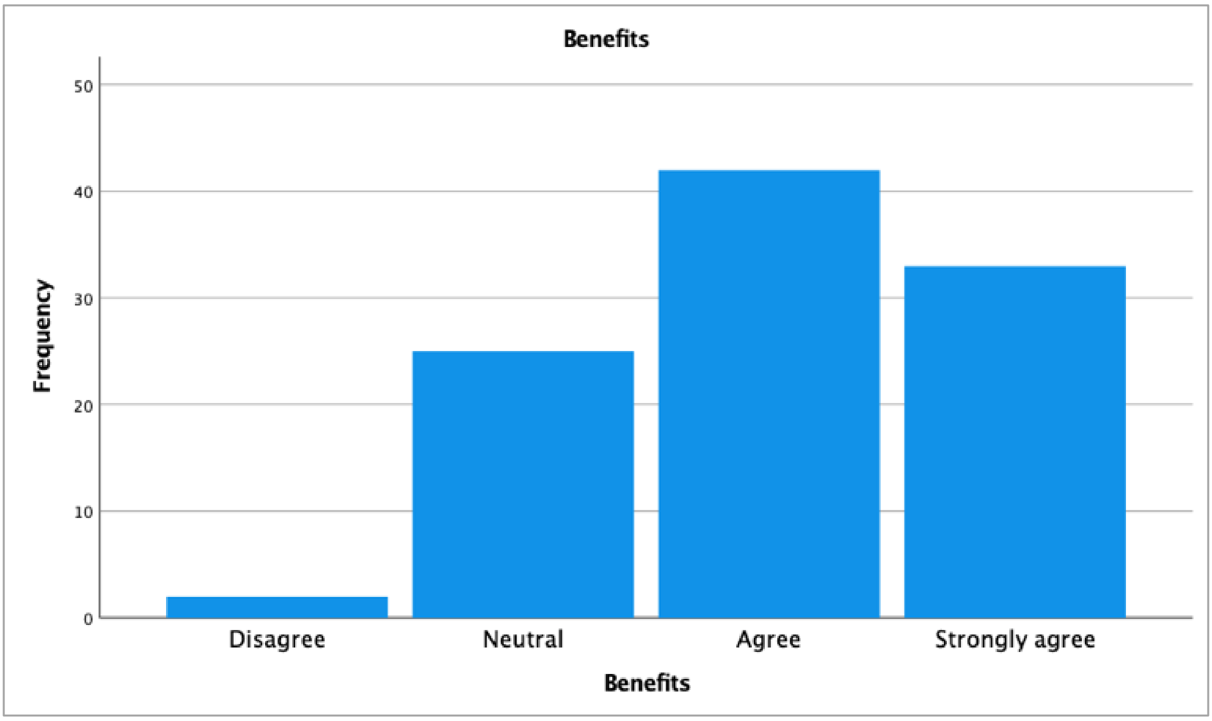
	Frequency	Percent
Strongly disagree	1	1.0
Disagree	11	10.8
Neutral	24	23.5
Agree	37	36.3
Strongly agree	29	28.4
Total	102	100.0

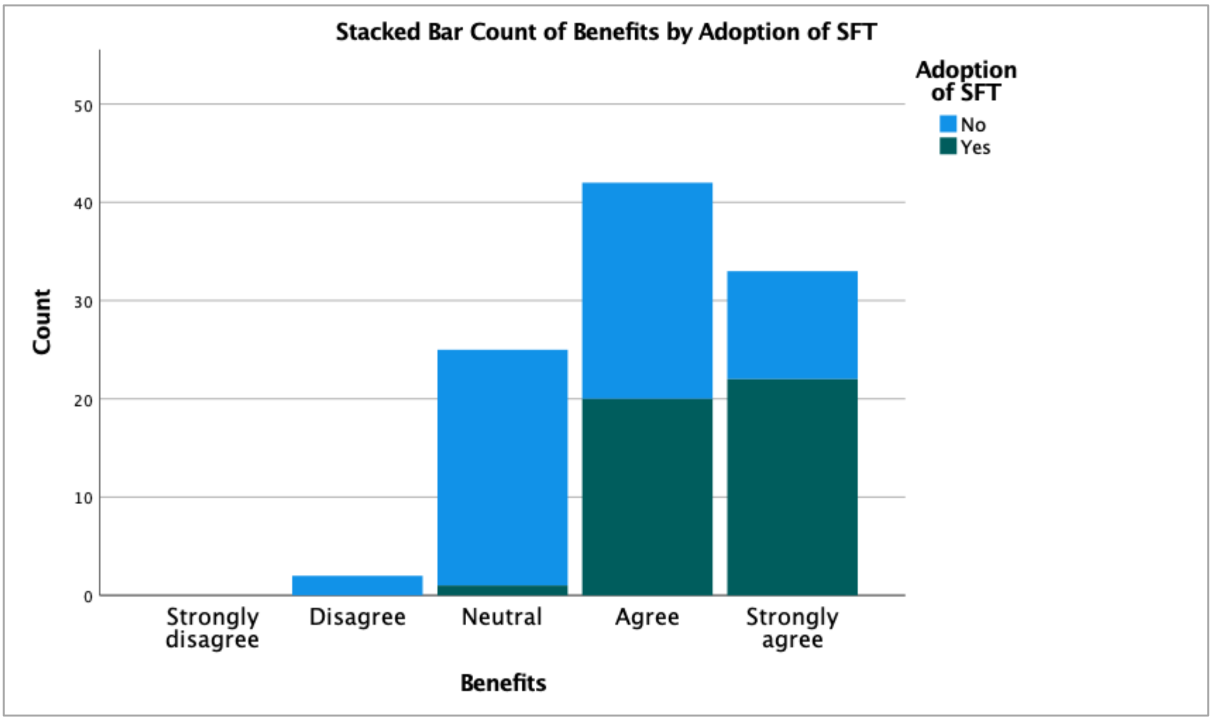




Benefits

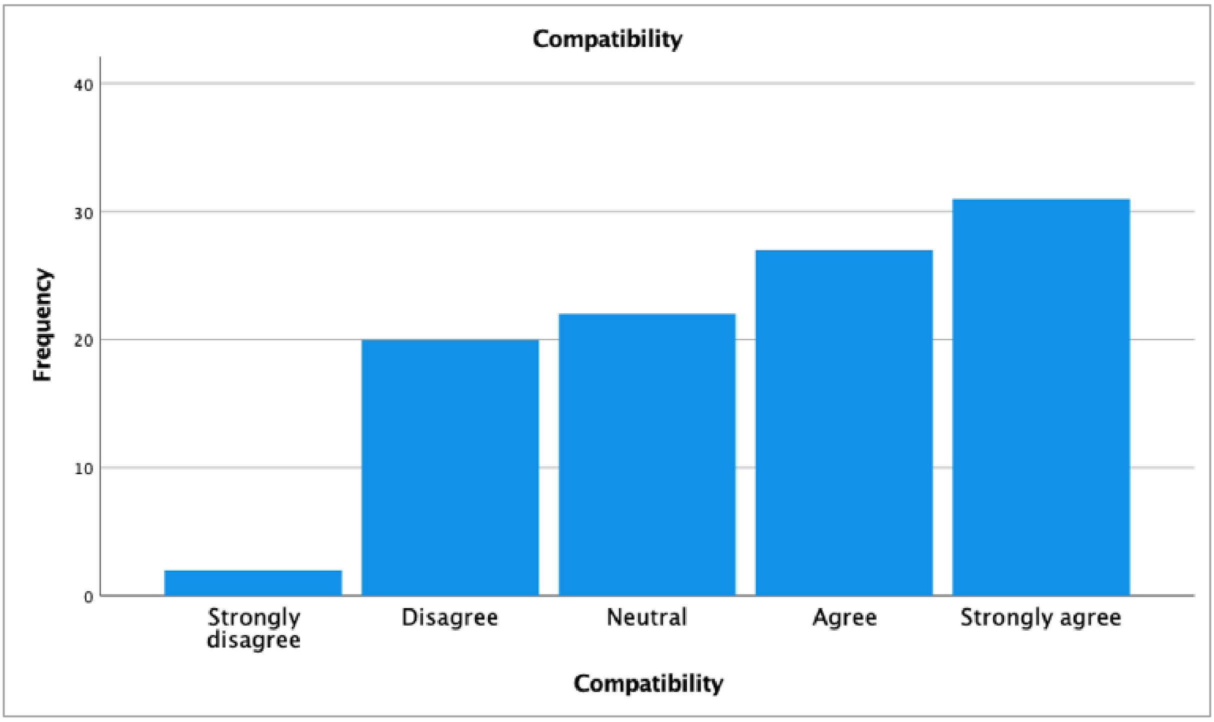
	Frequency	Percent
Disagree	2	2.0
Neutral	25	24.5
Agree	42	41.2
Strongly agree	33	32.4
Total	102	100.0

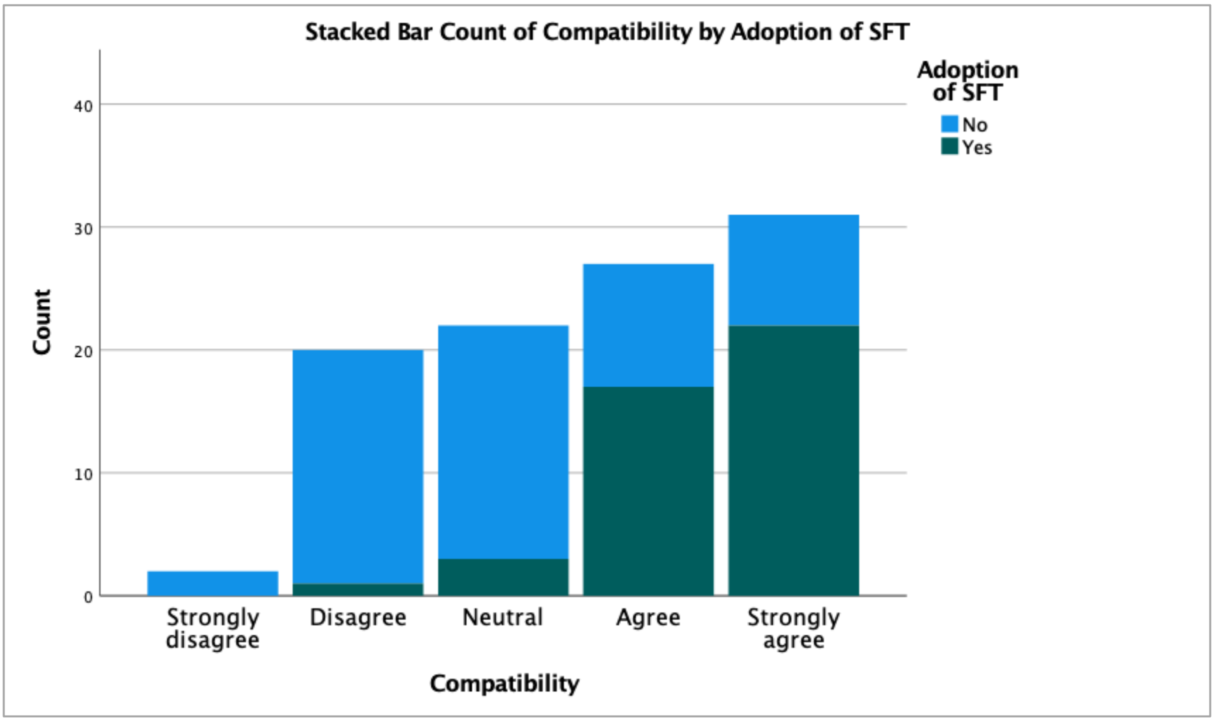




Compatibility

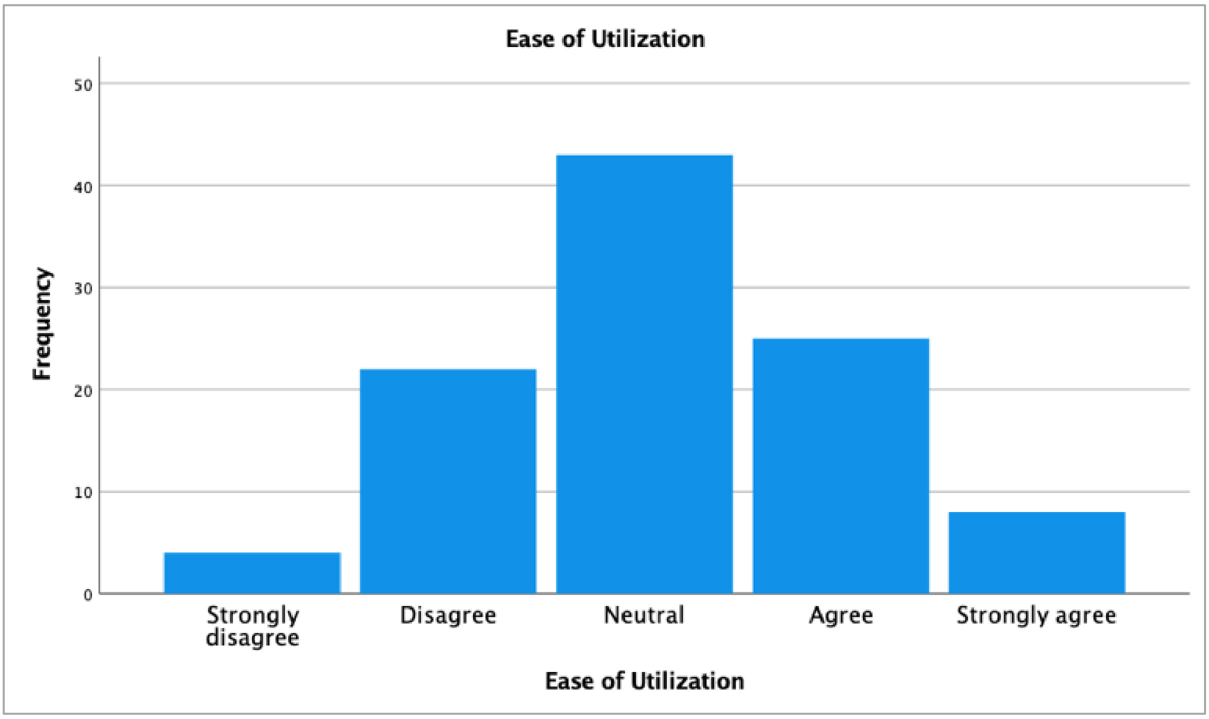
	Frequency	Percent
Strongly disagree	2	2.0
Disagree	20	19.6
Neutral	22	21.6
Agree	27	26.5
Strongly agree	31	30.4
Total	102	100.0

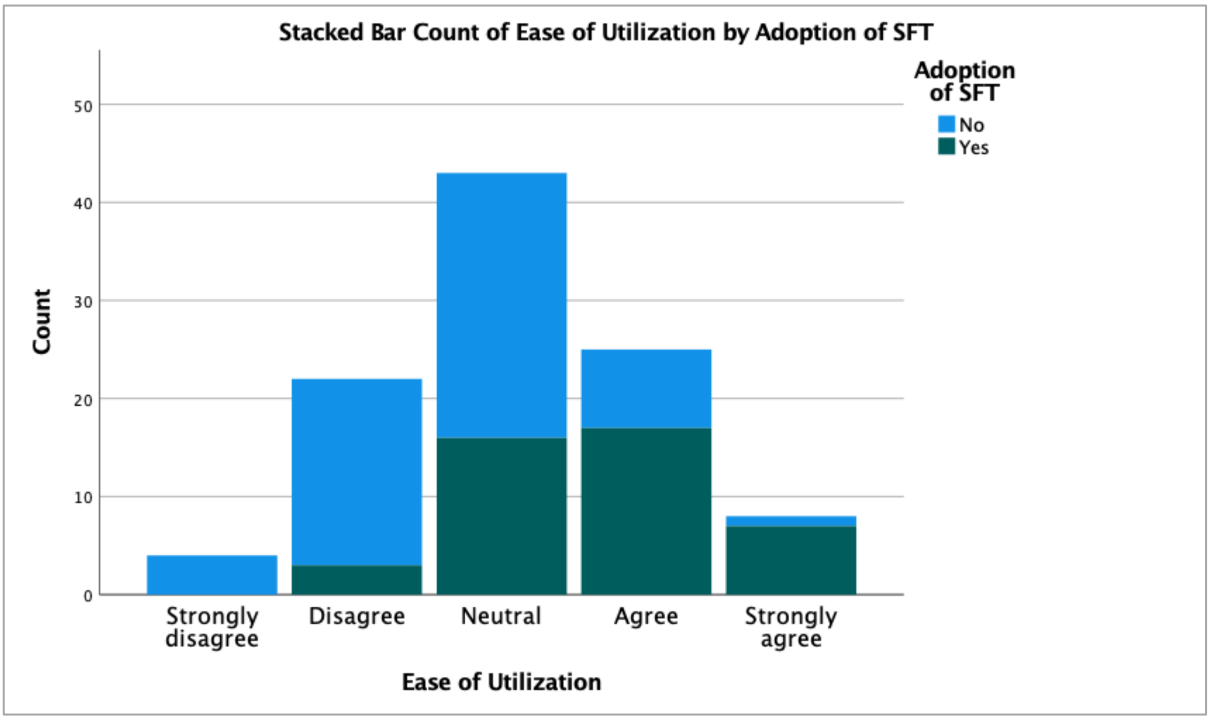




Ease of Utilization

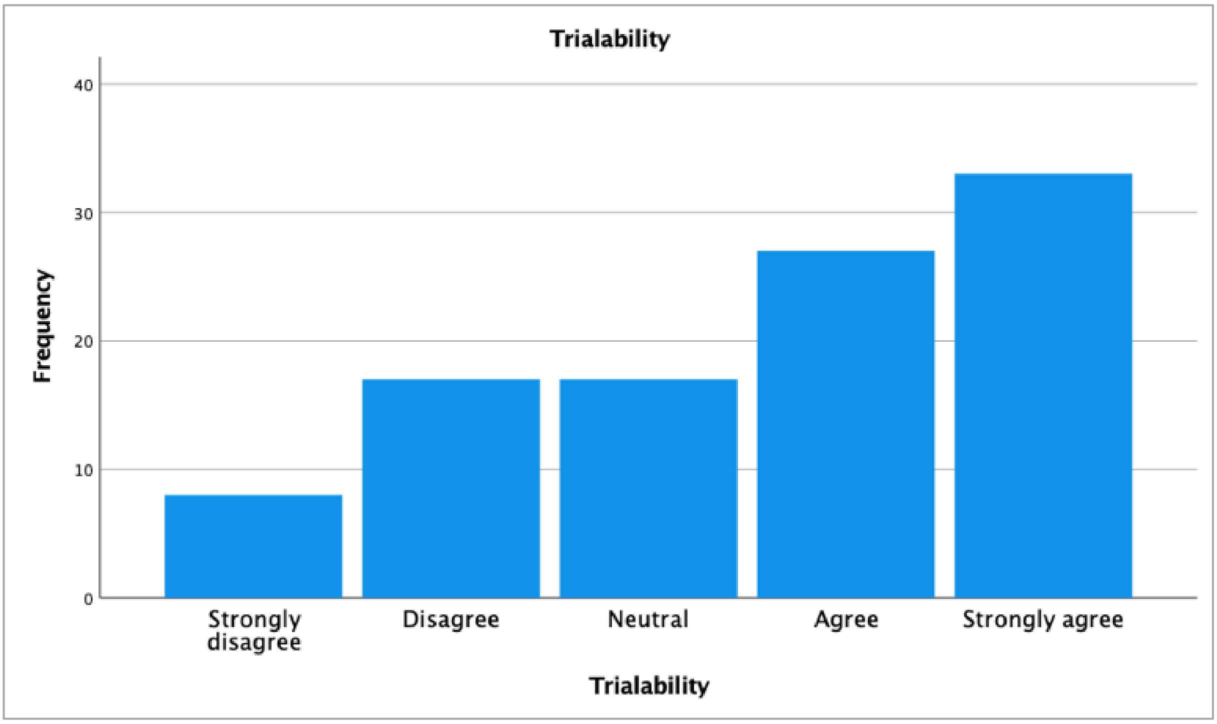
	Frequency	Percent
Strongly disagree	4	3.9
Disagree	22	21.6
Neutral	43	42.2
Agree	25	24.5
Strongly agree	8	7.8
Total	102	100.0

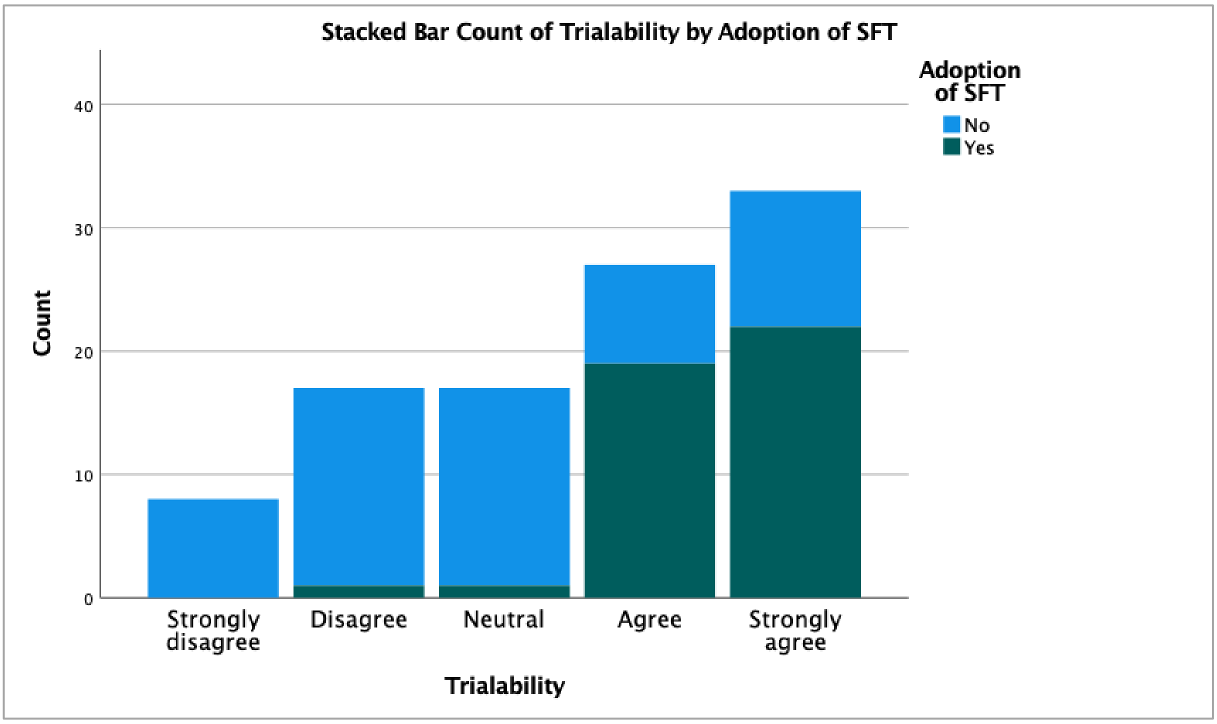




Trialability

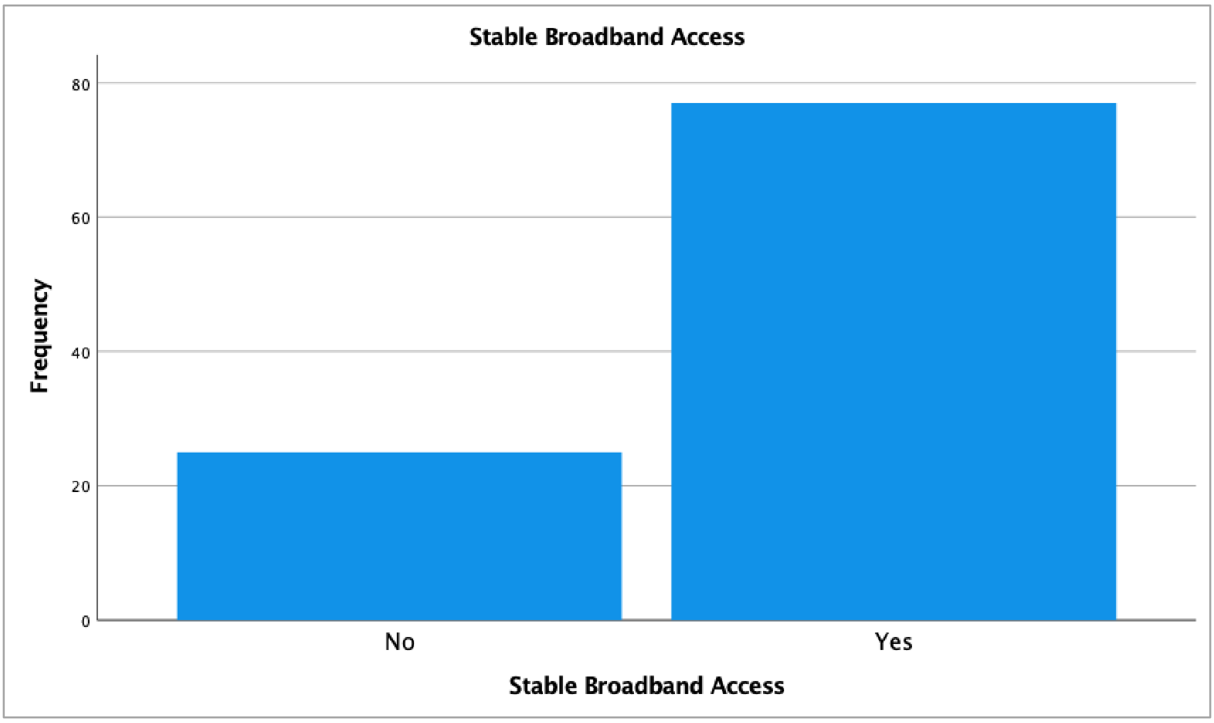
	Frequency	Percent
Strongly disagree	8	7.8
Disagree	17	16.7
Neutral	17	16.7
Agree	27	26.5
Strongly agree	33	32.2
Total	102	100.0

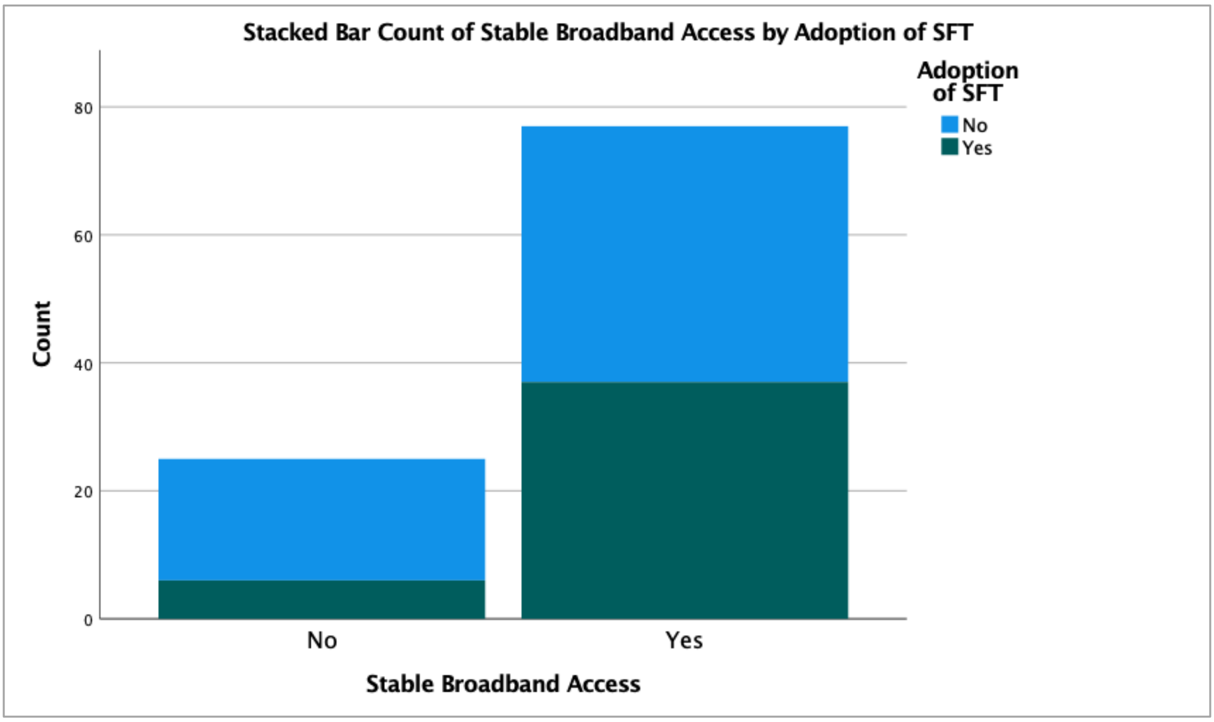




Stable Broadband Access

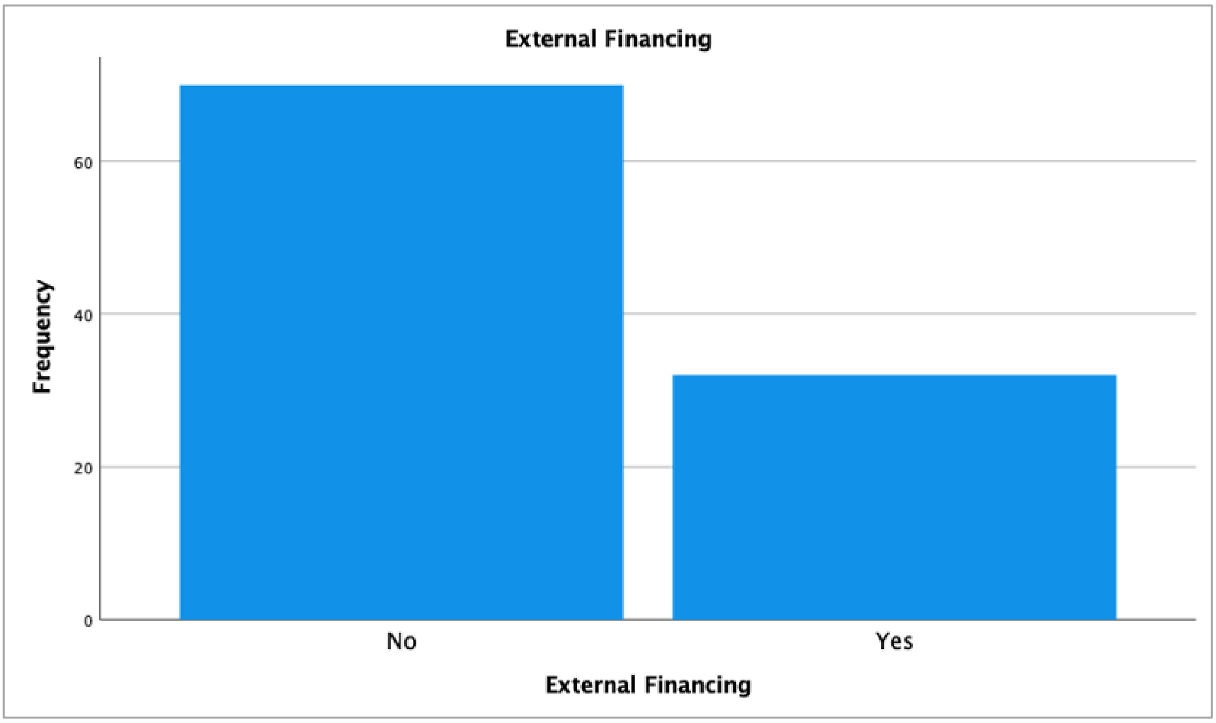
	Frequency	Percent
No	25	24.5
Yes	77	75.5
Total	102	100.0

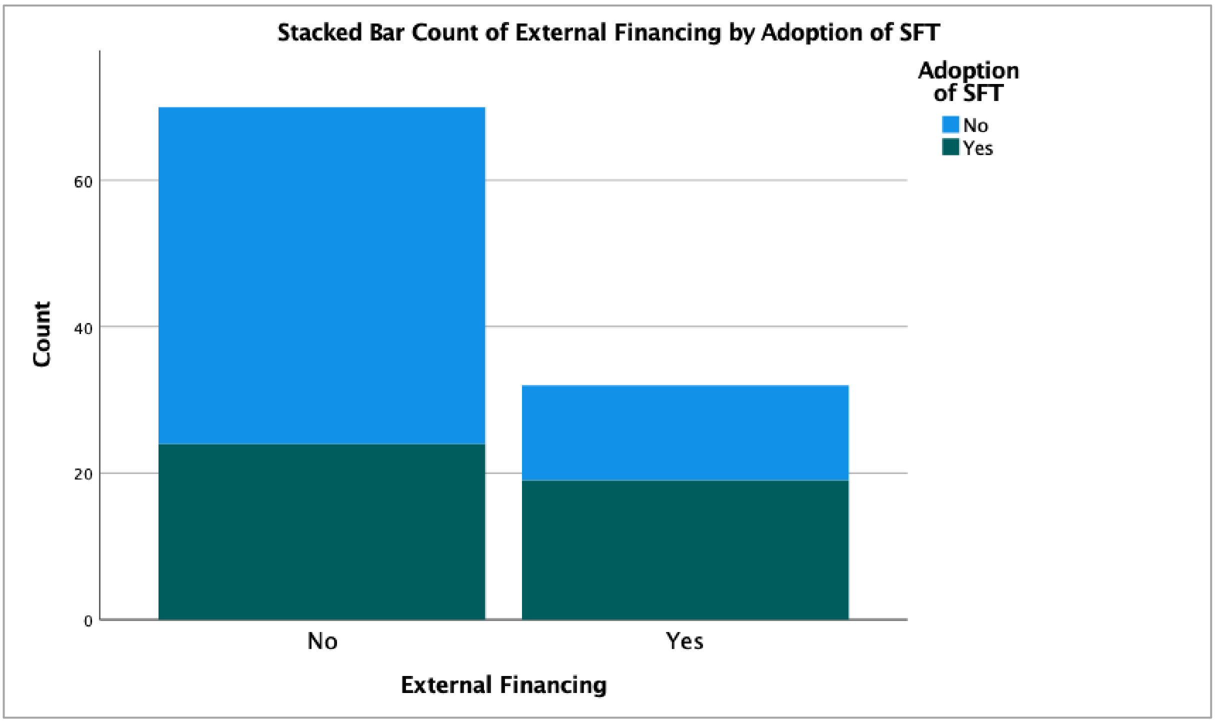




Awareness of External Financing

	Frequency	Percent
No	70	68.6
Yes	32	31.4
Total	102	100.0





Awareness of Information and Training Programs

	Frequency	Percent
No	67	65.7
Yes	35	34.3
Total	102	100.0