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Drivers of Innovation Adoption for Sustainable Agriculture

Running head: DRIVERS OF INNOVATION ADOPTION FOR SUSTAINABLE AGRICULTURE

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Abstract

Sustainability is defined as meeting the human needs of current as well as future generations. This anthropocentric perspective leads to joint objectives between sustainability and ergonomics. In the present study, we adopted a systems ergonomic approach and, based on the Theory of Planned Behavior, we analyzed the paths by which the information environment can affect farmers' adoption of sustainable measures through the mediation of attitudes, social pressure, and behavioral control. One hundred ninety-nine Italian farmers completed a questionnaire assessing exposure to impersonal, personal-formal, and personal-informal sources of information on the one hand and attitudes, perceived behavioral control, and subjective norms toward the adoption of two types of sustainable innovations (technological solutions and organizational/managerial practices) on the other. The results showed that attitudes and perceived behavioral control were the dominant determinants of farmers' adoption behavior, and personal-formal sources of information were positively associated with perceived behavioral control. Possible interventions are discussed for farmers' information environment to promote the adoption of sustainable innovations.

Keywords: Innovation adoption; Systems ergonomics; Sustainable agriculture; Theory of Planned Behavior; Italy.

Introduction

For most of human history (and prehistory), the size of the world population was small enough that humans did not suffer from a significant loss of resources, since they could relocate or resources could naturally regenerate. However, as the human population grew, the pressures on resources increased, and the problem of sustainability arose (Thatcher & Yeow, 2016). Sustainability is mainly an issue of resource scarcity or damage, either at present or at some time in the future (Dekker, Hancock, & Wilkin, 2013). Sustainable development has been defined by Brundtland's World Commission on Environment and Development (World Commission on Environment and Development, 1987) as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (p. 41), and it is often operationalized as a triple bottom line, maintaining the balance among the three pillars of economic, environmental, and social capital, to achieve development that is sustainable over a significant period of time (Lange-Morales, Thatcher, & García-Acosta, 2014).

Policymakers have integrated sustainability principles into regulations governing agricultural systems. In 1990, the US Congress promulgated the Farm Bill, which applied the concept of sustainability to the agricultural sector, defining agricultural sustainability as an "integrated system of plant and animal production practices having a site specific application that will, over the long term: (a) satisfy human food and fiber needs; (b) enhance environmental quality; (c) make efficient use of non-renewable resources and on-farm resources and integrate appropriate natural biological cycles and controls; (d) sustain the economic viability of farm operations; and (e) enhance the quality of life for farmers and society as a whole" (Public Law 101–624, Title XVI, Subtitle A, Section 1603, Senate and House of Representatives of the United States of America, 1990). Since 1992, the European Union has progressively integrated the sustainability principles in the Common

Agricultural Policy, moving from price and production support to a policy of direct income aid and rural development measures, including the so-called ‘agri-environment measures’, to encourage more rational land use and protection of the environment, with the aims of ensuring the delivery of environmental services, preserving the natural space and landscape, and preventing the abandonment of agricultural land (European Union, 2008).

Agri-environment commitment can be pursued through the adoption of both technological solutions and organizational/managerial practices (Lioutas & Charatsari, 2017). Technological solutions include all innovative technologies (e.g., farm equipment and irrigation technologies) that can be merged into the production process. Organizational/managerial practices refer either to changes in the organizational structure of a farm enterprise or to the application of new ideas, methods, and techniques in the way farming is practiced (e.g. the reuse of agricultural waste). Both of these types of measures have the potential to deliver more sustainable agricultural production and to boost agricultural productivity, based on a more precise and resource-efficient approach, thus representing a new lever to enhance common or growing trends in agricultural exploitations, such as family and organic farming (Knickel, Ashkenazy, Chebach, & Parrot, 2017). Therefore, fostering the adoption of these measures is considered a key element of the transition toward sustainable development by both policymakers and the business sector (Schaltegger, Etxeberria, & Ortas, 2017).

Despite their relevance, the uptake of these measures is still sporadic, and knowledge of the triggers of their adoption is underdeveloped (Burton, 2004a; Unay Gailhard, Bavorová, & Pirscher, 2015). At present, the literature has mainly focused on economic variables. According to a meta-analysis by Baumgart-Getz, Prokopy, and Floress (2012), investment is the best predictor of the adoption of sustainable practices. Somewhat consistently, according to Long, Blok, and Coninx (2016), costs hinder the adoption of climate-smart agricultural innovations and technologies.

Although farmers certainly have an interest in maximizing profit, the cost-benefit models cannot sufficiently capture the complexity of farmers' decision-making and behaviors. Indeed, farmers sometimes do not adopt a sustainable measure even though the economic evidence suggests they should and, vice versa, they adopt a sustainable measure even when the economic prospects are not clear or favorable (Flett et al., 2004; Wauters, Bielders, Poesen, Govers, & Mathijs, 2010). The failure of the models focused on economic triggers led to an increase in the application of new approaches in agricultural studies (Baumgart-Getz et al., 2012; Burton, 2004a), indicating the role played by social-psychological constructs such as attitudes, values, and goals in farmers' decision making (Unay Gailhard & Bojnec, 2016) and stressing the importance of considering these factors together with economic, environmental, social, and technological factors to contribute to the process of rural development (Chang et al., 2017; Jafry & O'Neill, 2000).

Ergonomics and its systems approach represent an effective perspective from which to investigate these issues. Ergonomics is the scientific discipline that applies theory, principles, data, and methods to evaluate and adapt the design of tasks, jobs, products, and environments to make them compatible with the needs, abilities, and limitations of people (see https://www.iea.cc/whats/index.html). To achieve this aim, a systems approach to understanding the interactions among people and all the other elements (artifacts, information, environments, or other people) within a defined context is adopted (ISO 9000:2015; Wilson, 2014). A fundamental issue in ergonomics is the evaluation of the efficiency of the system, defined as the resources expended in relation to the accuracy and completeness of goals achieved, which is one of the main components for the assessment of the usability of systems, products, and services (ISO 9241-11: 2018). Sustainable development and ergonomics share the joint objective of promoting an efficient allocation and use of resources, adopting a common anthropocentric perspective centered on human needs and actions (Thatcher & Yeow, 2016). The systems ergonomic approach can also provide a deeper understanding of the necessary behavioral changes required by societies to become sustainable (Hanson, 2013). In recent years, the ergonomic approach has been used fruitfully in the agricultural and forestry sectors, leading to significant improvement in work practices and to a significant increase in productivity through the standardization of agricultural equipment, machine design, and health and safety legislation (Baron, Estill, Steege, & Lalich, 2001).

In the present study, a systems ergonomic approach was adopted to analyze the relationships between social-psychological variables and the farmers' information environment about sustainable innovations to determine the best predictors of the adoption of technological solutions and practices for sustainable agriculture in a group of Italian farmers. The approach builds on the social-psychological Theory of Planned Behavior (TPB: see Ajzen, 1991) and the innovation diffusion theory (Rogers, 2010) to build and empirically test a fully mediated model aimed at predicting farmers' adoption of sustainable measures as a function of farmers' impersonal and personal (formal and informal) sources of information, with the mediation of attitudes, subjective norms, and perceived behavioral control. This analysis can suggest possible solutions in terms of policies, user-centered design of training, and information activities to support and promote the adoption of innovation for sustainable agriculture among the agricultural population (Daberkow & McBride, 2003; Lu, Yao, & Yu, 2005).

In the following section, we develop the research framework on the TPB and the role of different sources of information in innovation adoption. Then, the context of the study is described. Subsequent sections describe the methods applied (questionnaire) and the outcome of the study. Finally, the results are discussed, and conclusions are derived in the last two sections.

Theoretical background

Based on the increasing importance of the social-psychological perspective in the investigation of the uptake of sustainable measures (Burton, 2004a), in the present study, we performed our analysis by referring to the Theory of Planned Behavior (Ajzen, 1991), which has been widely used to predict and explain a specific behavior. According to the TPB, human action is guided by the degree to which the execution of the behavior is positively or negatively evaluated (attitude), by the perceived social pressure to engage or not to engage in the behavior (subjective norm), and by one's own perceived capability to perform the behavior successfully (perceived behavioral control). Together, these components lead to a positive or negative intention to perform the targeted behavior, which, in turn, efficiently predicts the actual behavior.

In recent years, the TPB has been fruitfully adopted in sustainable agricultural studies. Wauters et al. (2010) showed that farmers' attitudes predicted the adoption of soil conservation practices in Belgium. Moreover, Menozzi, Fioravenzi, and Donati (2015) found that attitudes positively affected farmers' intentions to implement eco-friendly farming practices in Italy, whereas attitudes and perceived behavioral control predicted the intention to adopt voluntary sustainability schemes. Finally, in their study of the adoption of green innovations in Greece, Lioutas and Charatsari (2017) noted that subjective norms did not affect the adoption decision.

However, in these studies, external factors influencing attitudes, subjective norms, and perceived behavioral control have been underinvestigated. A relevant role could be played by the potential users' exposure to different sources of information, in that this variable has been shown to be a key factor in a wide range of decision-making situations

(Rogers & Beal, 1958). Moreover, information asymmetry has been listed among the barriers to the diffusion of technological innovations, both in agriculture and in other fields (Long et al., 2016; Lu et al., 2005; Tabrizian, 2019).

Regarding innovation adoption, in the present study, we built on the innovation diffusion theory developed by Rogers (2010) to investigate the role played by information sources on farmers' adoption of sustainable measures. Moreover, based on the "Guidelines for Collecting and Interpreting Innovation Data" of the European Community Survey (Organisation for Economic Co-operation and Development [OECD], 2005), we considered innovation the implementation of a relevantly improved product, process, or method in business practices, productive organizations, or relations. Thus, consistent with Genius and Pantzios (2014; see also Unay Gailhard et al., 2015), we considered innovations to be not only technological developments, which are typically considered a disruptive advancement in agriculture (Cavallo, Ferrari, & Coccia, 2015), but also agri-environmental practices and strategies and organizational and managerial procedures, which are innovative and can enhance the environmental sustainability of a production activity (Biddoccu, Opsi, & Cavallo, 2014; Pulina et al., 2018).

According to Rogers (2010), the diffusion of innovation is the "process by which an innovation is communicated through certain channels over time among the members of a social system" (p. 46). Information is shared with potential users through two main channels: one impersonal channel (i.e., without a direct face-to-face exchange, such as the mass media) and one personal channel (i.e., communication contacts that involve a direct face-to face exchange). Personal contacts can be further divided into informal contacts with relatives and peers and formal contacts with institutionalized sources. Valente (1995) defines the diffusion of innovation as a communication process in which an adopter persuades those who have not yet adopted to adopt. Through the communication channels, potential users are at first exposed to an innovation, and if they are interested, they actively seek related information. Then, the individual weighs the advantages/disadvantages of using the innovation and decides whether to adopt or reject the innovation. Then, he/she finalizes his/her decision to continue using the innovation.

The few studies referring to Rogers' (2010) constructs for the adoption of sustainable measures in agriculture showed that impersonal communication is the major source of knowledge about an innovation (Defrancesco, Gatto, Runge, & Trestini, 2008; McBride & Daberkow, 2003), while personal contacts are more effective in forming and changing attitudes toward a new idea and thus in influencing the decision to adopt or reject it (McBride & Daberkow, 2003). In addition, personal contacts are more effective than the impersonal channel in enhancing users' innovativeness and adoption behavior, since they involve users in a more direct way, thus making it difficult to ignore the message (Unay Gailhard et al., 2015).

Regarding formal and informal personal sources, contrasting results have been reported. Some studies have shown that farmers who participate in formal organizations are more inclined to adopt different types of innovations (Jallow, Awadh, Albaho, Devi, & Thomas, 2017; Unay Gailhard, Bavorová, & Pirscher, 2012), whereas other research has noted the higher efficacy of frequent informal contacts (Defrancesco et al., 2008; Polman & Slangen, 2008). However, in these studies, the role of the information environment has usually been analyzed through discrete choice (logit or probit) models, while only mediated models allow the researcher to detect the reason for the association between the independent and dependent variables.

Hypotheses

The research conducted by Rogers (2010) showed that innovation adoption starts with diffusion through communication channels. Since the adoption behavior is one type of behavior and the TPB postulates three components that explain a behavior (Ajzen, 1991), we tested the following hypotheses:

H1: Having received information will show a positive association with attitudes toward adoption;

H2: Having received information will show a positive association with subjective norms toward adoption; and

H3: Having received information will show a positive association with perceived behavioral control over adoption.

Given the inconsistent results in the extant literature, we made no specific hypotheses regarding the association between each different source of information and attitudes, subjective norms and perceived behavioral control.

According to the TPB (Ajzen, 1991), people who have positive attitudes toward the behavior, who think that there is normative support for it, and who perceive that they can easily perform it should have strong intentions to perform the behavior. Accordingly, we developed and tested the following hypotheses:

H4: Positive attitudes will show a positive association with adoption;

H5: Higher perceived behavioral control will show a positive association with adoption; and

H6: Higher social pressure (i.e., subjective norms) will show a positive association with adoption.

Considering the variety of sustainable measures listed in the literature (Lioutas & Charatsari, 2017; Unay Gailhard et al., 2015; Wauters et al., 2010), the model parameters were tested across two different types of sustainable measures: technological solutions and organizational/managerial practices (Lioutas & Charatsari, 2017). This approach allowed us to determine whether the decision-making process varies for the different investigated measures and to eventually note the critical variables to be addressed with targeted interventions to promote farmers' adoption of each type of sustainable measure.

Context of the study

We investigated the abovementioned issues in a sample of Italian farmers. Europe is a particularly relevant context to investigate the issues related to the adoption of sustainable measures, since the environmental objectives have become increasingly integrated into the EU's Common Agricultural Policy, leading to an augmented importance of understanding and anticipating the response of individual actors to policy measures integrating sustainable practices (Burton, 2004a; Defrancesco et al., 2008; Long et al., 2016). Among the EU-28 countries, Italy has the second-largest agriculture, with a turnover of more than EUR 55 billion in 2015 (Eurostat, 2016). Italian farmers are generally not deeply oriented toward environmental protection and sustainability (Menozzi et al., 2015). Within Italy, the Piedmont region (northwestern Italy) offers an apt representation of the Italian farming system and rural population, since it includes approximately 10% of the total Italian utilized agricultural area and over 61,000 out of the 1,620,884 Italian agricultural holdings operate in this region (Istituto Nazionale di Economia Agraria [INEA], 2014).

Materials and methods

Participants and setting

The study involved a sample of 199 male farmers. Table 1 summarizes their characteristics. The participants were recruited among the visitors of the 37th National Exhibition of Agricultural Mechanization in Savigliano, the largest agricultural machinery exhibition in the Piedmont region. The 2018 edition of the show (March 15-18) was attended by over 60,000 visitors, with an exhibition area of approximately 49,000 m^2. The Savigliano Exhibition is a public event that mostly features equipment but also attracts people and families because of its recreational and entertaining activities. Agricultural exhibitions play an important role in the life of Italian small country towns, where they often combine amusement elements, breeding stock exhibitions and sports happenings, with lectures, seminars and conferences. These features make this kind of agricultural exhibitions a suitable place for survey and data collection (Caffaro, Micheletti Cremasco, Roccato, & Cavallo, 2018a; Cavallo, Görücü, & Murphy, 2015; Ferrari, Spinelli, Cavallo, & Magagnotti, 2012; Reichardt, Jürgens, Klöble, Hüter, & Moser, 2009; Reichardt & Jürgens, 2009).

Instrument

Participants were administered a 21-item paper-and-pencil questionnaire (see Appendix 1) that was pilot-tested before use. The questionnaire was composed of 4 sections. In the first section, participants had to choose from a list of six sustainable measures the one that they had already experienced or used or had heard about. The six measures represented two types of innovations: technological improvements (sensors and apps, systems for precision agriculture, and systems for diesel engine exhaust gas emission abatement) and organizational/managerial practices (use of organic fertilizers, conservation tillage, and rational use of water). These six measures were chosen to represent the different types of sustainable innovations described by Lioutas and Charatsari (2017), and they emerged as the most frequently cited measures in previous studies regarding agricultural sustainability in different European countries (Lioutas & Charatsari, 2017; Unay Gailhard et al., 2015; Wauters et al., 2010).

After this choice, the participants were asked to indicate whether they actually used or intended to use the measure they had chosen on a 4-point rating scale based on McDonald and Alpert (2001) (0: I do not use it and do not intend to adopt it; 1: I do not use it, but I may adopt it in the future; 2: I do not use it, but I am planning to adopt it; 3: I have already adopted it in my farm).

In the second section of the questionnaire, building on Adrian, Norwood, and Mask (2005) and on Ajzen (2002), participants had to report on a 4-point scale (ranging from 1: I not at all agree to 4: I completely agree) their agreement with the following 3 statements regarding their attitude toward the chosen measure: adopting this measure is useful for farm operations, adopting this measure is beneficial for farm operations, and adopting this measure is stressful. These items were designed to represent both the instrumental and experiential components of the overall attitude toward a behavior (Ajzen, 2002).

In the third section, subjective norms and perceived behavioral control (Ajzen, 2002) were measured. Based on the scales developed by Lioutas and Charatsari (2017), the participants had to indicate on a 4-point scale (from 1: not at all true to 4: completely true) how true they considered the following statements about the possible reasons to adopt the chosen measure: being motivated by my friends, because people around me adopted it, I want to keep up with the new trends within my community, I want to enjoy the appreciation of my peers, I did not want to be the last to adopt it, I had the expertise needed to apply it, and I thought it would be easy to deal with it.

In the fourth section, the participants had to indicate on a 4-point scale (1: never, 4: often) how often they were exposed to the following different sources of information about the chosen measure: exhibitions, journals/advertisements/internet, training courses, discussions with peers/relatives, and discussions with consultants/trade organizations. These sources of information were selected based on those emerging from the literature and previous studies as the most recurrent sources of information about innovation among farmers (Rogers & Beal, 1958; Unay Gailhard et al., 2012). Based on Rogers and Beal (1958), we expected the following factorial structure of the battery: discussions with peers/relatives to load on one factor (i.e., ‘personal-informal’); training courses, discussions with consultants/trade organizations to load on another factor (i.e., ‘personal-formal’); and journals/advertisements/internet and exhibitions to load on another factor (i.e., ‘impersonal’).

A standard sociodemographic form that assessed participants’ work-related characteristics (profession, years of experience in the agricultural sector and farm size) ended the questionnaire.

Procedure

Trained research assistants provided the questionnaire to exhibition attendees. The assistants explained the aims of the study and informed the participants that the questionnaire was anonymous. The questionnaire was in Italian, and its completion took approximately 5-6 minutes. No incentive was offered to participate in the survey. The response rate was approximately 90%.

Data analysis

We tested our hypotheses via a series of path analyses and utilized Amos 20 (Arbuckle, 2014). Path analysis is an extension of multiple regression that is particularly effective in the pursuit of our goals for reasons that are twofold. First, path analysis allows us to test mediated models, i.e., models in which some variables (in our case, the sources of information) are postulated as causes, other variables are postulated as effects (in our case, the adoption of agri-environmental sustainable innovations), and still other variables are postulated as mediators, i.e., as effects of the former and causes of the latter (in our case, the attitudes toward the adoption, the subjective norms about the adoption, and the perceived behavioral control over the adoption). Second, path analysis allows for the testing of the fit of the model to the data, giving the researcher much richer diagnostic information on the model than that available in the multiple regression approach. We estimated our models using the maximum likelihood estimate, which facilitates the identification of the parameters that maximize the likelihood function linking the model to the observations.

We considered parameters with an associated p value < .05 to be significant. The fit of the model was tested by combining different indices: the incremental fit index (*IFI*; Bollen, 1990); the comparative fit index (*CFI*; Bentler, 1990); and the root mean square error of approximation (*RMSEA*; Steiger, 1990). Based on the guidelines proposed by Bentler (1990), we considered the *IFI* and the *CFI* to be satisfactory if they were higher than .90. The *RMSEA* was considered satisfactory if it was lower than .05 and acceptable if it was lower than .08. With the exception of the tests of structural invariance (see below), when evaluating the overall fit of the model, we did not take into consideration the χ^2, since its significance depends on the sample size.

Moreover, we tested the structural invariance of the model across the two types of sustainable measures we analyzed. As suggested by Reise, Widaman, and Pugh (1993), we first tested the fit of a *baseline model*, in which the model was tested simultaneously in the participants who answered the questionnaire making reference to technological solutions (sensors/apps, precision agriculture, and emission abatement) and in those who answered the questionnaire making reference to organizational/managerial practices (use of organic matter, conservation tillage, and rational use of water). Subsequently, we tested the fit of an *invariant model*, in which all the parameters were constrained to be equal across the two groups of sustainable measures. The model was considered invariant if the difference in the χ^2 of the invariant model and of the baseline model did not reach statistical significance for a number of degrees of freedom (DF) equal to the difference in DF of the two models. In this case, we could indeed conclude that constraining the model's parameters to be equal across the two groups of participants did not lead to a significant worsening in the model's

360 fit. In this case, the use of the χ^2 did not lead to a distortion, since the *N* of the two models
361 was the same.

362 **Results**

363 Table 2 reports the descriptive statistics for the variables we measured and their
364 correlations.

365 As a first step, we tested the model we described in the Hypotheses paragraph.

366 Some of the parameters of such an initial model did not reach statistical significance.
367 Moreover, this model's fit was not satisfactory ($\chi^2(9) = 124.14$, $p < .001$, $IFI = .24$, $CFI =$
368 $.18$, $RMSEA = .25$, 90% $CI = .22, .30$). Thus, we performed a series of other path analyses,
369 progressively deleting the variables that had nonsignificant associations with the predicted
370 variables and/or those worsening the fit of the model. These analyses led us to obtain the
371 model displayed in Figure 1. All of its parameters were statistically significant (all *p*s <
372 .05), and its fit was satisfactory ($\chi^2(4) = 6.78$, $p = .15$, $IFI = .97$, $CFI = .97$, $RMSEA = .06$,
373 90% $CI = .00, .13$). Thus, we considered it our final model. Unidirectional arrows
374 represent regression betas, and bidirectional arrows represent correlations.

375 Contrary to H1, impersonal information showed a negative association with attitude
376 toward adoption. Contrary to H2, none of the sources of information showed a significant
377 association with our social-psychological variables. However, consistent with H3,
378 exposure to personal-formal information was positively associated with perceived
379 behavioral control. Consistent with H4 and H5, respectively, attitude toward adoption and
380 perceived behavioral control showed a positive association with participants' intention to
381 adopt agri-environmental sustainable innovation. However, contrary to H6, subjective
382 norms about adoption did not show a significant association with the dependent variable.
383 Bootstrap estimation (500 samples) showed that both of these indirect associations were
384 significant (*indirect effects* = .03, $p = .01$ and *indirect effects* = -.03, $p = .01$, respectively).

385 The model explained approximately 11% of the variance of the dependent variable (R^2 = .11). Figure 1 shows the parameters we analyzed.

387 Table 3 shows that our final model's parameters were invariant across the type of sustainable measures (technological solutions and organizational/managerial aspects).

389 **Discussion**

390 In this study, we adopted a human-centered systems ergonomics perspective to investigate the drivers of the adoption of sustainable measures in a sample of Italian farmers. Although the explicit reference to the concept of sustainable development is relatively new in ergonomics, the underlying ideas and approaches are not, particularly the systems approach (Thatcher & Yeow, 2016). Indeed, the identification and visualization of links and relationships between the different human-technical components of the system may support the management of drivers and indicators that precede key social and environmental impacts (Schaltegger et al., 2017).

398 In particular, we analyzed the effects of the interaction between subjective factors considered in the TPB (Ajzen, 1991) and the exposure to different sources of information considered in Rogers' theory about innovation diffusion (Rogers, 2010) to identify critical paths and components that may benefit from user-centered interventions (ISO 9241-11:2018) aimed at enhancing the adoption of sustainable innovations in farming.

403 The results showed that exposure to impersonal and personal-formal information sources was associated with attitudes toward adoption and perceived behavioral control, which in turn were positively associated with the adoption of sustainable measures. In particular, personal-formal contacts had a positive association with perceived behavioral control, whereas impersonal information sources had a negative association with attitudes.

408 More specifically, the positive association between exposure to formal personal sources of information (e.g., farmers' associations and training courses) and the adoption

of a sustainable measure is consistent with previous results by Unay Gailhard et al. (2015), which showed that an effective diffusion of information on organic farming could be expected among German farmers when they were approached by formal organizations. This positive association also confirms McBride and Daberkow's (2003) evidence that technical (or "how-to") information from sources including vendors and professional consultants were the most important to the potential adopters of precision farming technologies among US farmers.

This result could be interpreted by considering Roger's (2010) concepts of homophily and heterophily and their role in innovation diffusion and adoption. Homophily is the degree to which a pair of individuals who communicate are similar, whereas heterophily is the degree to which pairs of individuals who interact are different in certain attributes. In the diffusion of innovation, the participants are usually quite heterophilous (a consultant, for instance, is more technically competent than his/her clients), and this information asymmetry (Tabrizian, 2019) frequently leads to ineffective communication because the two individuals do not speak the same language. However, when two individuals are identical regarding their technical grasp of an innovation, diffusion cannot occur, as there is no new information to exchange. Thus, the nature of diffusion demands that at least some degree of heterophily be present between the two participants in the communication process (Rogers, 2010). Formal communication in our sample appeared to be successful in helping individuals overcome informational asymmetry, since it enhanced our participants' perceived behavioral control of the innovation, fostering further investigations on how the information is provided to potential users, i.e., the key messages conveyed and the media through which they are disseminated.

The significant effect of perceived behavioral control on innovation adoption is consistent with that stemming from the study by Fielding, Terry, Masser, and Hogg (2008), which found that perceived behavioral control was a significant predictor of the intention to engage in riparian zone management among Australian farmers. As noted by Rogers (1976), the topic of control is strictly interwoven with the concept of development, which can be defined as "a widely participatory process of social change in a society intended to bring about both social and material advancement (including greater equality, freedom, and other valued qualities) for the majority of people through their gaining greater control over their environment" (p.224). Enabling farmers to perceive the adoption of innovative farming measures as being under one's own volitional control appeared in our study to be a key concept promoting sustainable development in agriculture, and it shall be pursued through user-centered institutionalized communication activities built on the limits and capabilities of the potential users (Agbedahin, 2019). Similar to the proposal of Hickman, Rogers, and Fisk (2007) regarding training on a hydroponic garden control system, some practical training could also be proposed, with periodic refreshes when technological upgrades are released or new practices are introduced.

Based on the present results, personal sources of information may have a substantial capacity to influence farmers' decision-making about the adoption of sustainable measures, highlighting the need to involve farmers' associations and consultants in the organization of informative events and focused training activities to provide farmers with the skills needed to address different practices and innovations. Education has been acknowledged as the most powerful transformative force in the achievement of a sustainable future (Hopkins & McKeown, 2001). Education requires a participatory approach in teaching and in the development of training methods (Caffaro, Micheletti Cremasco, Bagagiolo, Vigoroso, & Cavallo, 2018b) to motivate and empower both apprentices and teachers to learn, reflect, change their behavior, and take action for sustainable development. The participation of stakeholders is deeply rooted in the vision of sustainable development as a collaborative process of involving stakeholders to initiate and diffuse the technical, organizational, and social innovations necessary for greater sustainable development, with regard to environmental, social, and economic aspects (Moss & Fichter, 2003).

On the other hand, the results of the study showed that impersonal sources of information (e.g., exhibitions, internet, and advertisements) affect the adoption of a sustainable measure through a negative association with attitude. The role played by attitude is consistent with those identified in previous studies applying the TPB to the agricultural domain, in which farmers' attitudes consistently emerged as an important predictor of the adoption of soil erosion control practices in Belgium (Wauters et al., 2010), riparian zone management in Australia (Fielding et al., 2008), and climate information use and water conservation activities in Iran (Sharifzadeh, Zamani, Khalili, & Karami, 2012; Yazdanpanah, Hayati, Hochrainer-Stigler, & Zamani, 2014). The present result highlighted the importance of understanding farmers' attitudes to effectively promote the adoption of sustainable innovations. Further insights into the critical factors in the development of attitudes will be necessary to design policy measures that can alter farmers' attitudes and thus promote engagement in sustainable practices.

Innovatively, compared to the existing literature, impersonal sources of information showed a negative association with attitudes. Information disseminated by the mass media is usually the most common channel through which farmers are made aware of the existence of an innovation (McBride & Daberkow, 2003). Ineffective communication at this level can lead to a lack of awareness, resulting in failed diffusion and lower rates of adoption (Rogers, 2010). Based on the present results, it is possible that current traditional argument-based communication campaigns should be reconsidered, and tailored communication approaches that take different farmers' attitudes into account could be recommended (Jansen, Renes, & Lam, 2010). As suggested by Menozzi et al. (2015), a peripheral route of communication using implicit persuasion techniques (Jansen et al., 2010), which is recommended when farmers are less motivated to perform the desired behavior, could also be appropriate.

Personal-informal sources of information did not show any significant relationships with attitudes, subjective norms, perceived behavioral control, and the adoption of a sustainable measure. Similarly, subjective norms did not show any association with adoption. At first glance, the lack of association between personal-informal sources of information and the dependent variable could appear somewhat surprising, since the literature showed that interpersonal informal networks comprising friends and colleagues represent an important source of information (Unay Gailhard et al., 2012, 2015). On the other hand, the result regarding subjective norms is consistent with the evidence of the meta-analytic review about TPB (Armitage & Conner, 2001), which noted that subjective norms were the weakest predictor of actual behavior, as well as with the results of previous studies applying the constructs of TPB to the agricultural sector (Lioutas & Charatsari, 2017; Menozzi et al., 2015; Wauters et al., 2010). The nonsignificant effects of informal communication and subjective norms could be interpreted by considering that farmers attribute high importance to independence (Caffaro et al., 2018c; Sullivan, 1996) and often perceive themselves as uninfluenced by neighboring farmers' opinions and behaviors (Burton, 2004a, 2004b). This evidence may suggest that key stakeholders in sustainability promotion (e.g., public authorities) should improve the involvement of farmers in exchanging information and sharing the benefits of implementing sustainable measures.

On a related note, our model was invariant across the two different types of sustainable measures considered. Further investigations that widen the range of sustainable measures surveyed could be interesting. At present, however, based on our results, sustainable measures diffusion appears to be a general process that displays patterns and regularities that are not bound by the type of innovation studied (Rogers, 2004). Thus, we provisionally conclude that communication interventions aimed at widening the adoption of sustainable measures do not need to be tailored to the characteristics of the specific measure one aims to promote.

Limitations of the study and future research developments

Some limitations of the present study should be acknowledged. First, the participants were farmers only from the Piedmont region and were not chosen via a random sampling procedure. However, the suboptimal representativeness of our sample could be less problematic than it may appear at first glance for reasons that are twofold. First, previous studies have shown that farmers from Piedmont can be usefully surveyed to analyze the dynamics of the Italian farming population (Caffaro et al., 2018b). Second, we were interested in studying the relations between variables in at least bivariate analyses and not their absolute state as resulting from univariate analyses. In these cases, the bias stemming from the lack of complete representativeness of the sample is significantly less impacting (Roccato, 2008). Moreover, participants were selected among the visitors of an agricultural exhibition. Generally, according to the literature on social capital theory, one could expect that our sample was probably composed of farmers who are more open to innovative/new ideas relative to nonparticipants (Polman & Slangen, 2008). If this were true, our sampling process could lead to a selection bias. However, due to the very peculiar characteristics of the Savigliano exhibition (which combines amusement elements with seminars and conferences), we are confident that participants involved in the study nicely represent Italian farmers. Thus, as a whole, we are confident about the validity of our results. However, new research performed in additional regions of Italy and in other countries to obtain more generalizable results would be welcome.

534 Moreover, the findings of this study need to be interpreted with caution due to the
535 collection of cross-sectional data, which does not allow for the establishment of causal
536 links among the investigated variables. To address this issue, in a future development of
537 the research, a longitudinal design with a weekly recording of the exposure to different
538 sources of information about sustainable measures (e.g., exhibitions, training courses, and
539 informal communications) could be developed (similar to what has been developed for
540 farm accidents by Glasscock, Rasmussen, Carstensen, & Hansen, 2006), and the actual
541 adoption of the targeted innovations could be monitored over a longer time period.

542 Finally, in the present study, we relied on self-report data. Although self-reporting is
543 a common strategy in this kind of investigation (Defrancesco et al., 2008; Lioutas &
544 Charatsari, 2017; Menozzi et al., 2015) and in ergonomics research (Kirwan & Ainsworth,
545 1992), it might be that participants' responses were affected by memory bias. Thus, in a
546 future development of the research, it will be useful to triangulate (MacLeod, Wells, &
547 Lane, 2000) this kind of data with on-field observations to provide further consistent
548 results. Additionally, the recall of autobiographical memories stimulated by single words
549 or phrases, as discussed by Charatsari (2014), could be used in new research to investigate
550 farmers' attitudes toward sustainable innovations and their course over time.
551 Autobiographical memories indeed allow us to collect retrospective data that are less
552 vulnerable to response bias, since participants are not asked direct questions on the target
553 topic.

554 **Conclusions**

555 The choice to adopt sustainable innovations is a rather complex process among farmers,
556 that needs to be analyzed by integrating theories drawn from diverse fields of study, both
557 social-psychological and technical in nature. Some recommendations arise from the
558 present study: to encourage the adoption of innovations (regardless of whether it is

technological or organizational/managerial, Lioutas & Charatsari, 2017), it would be useful to adopt multidimensional measurements and a systems ergonomic approach focusing on the skills needed to empower farmers and enhance their perceived control of the innovation. In addition, information campaigns could be developed adopting a bottom-up participatory approach to the diffusion of innovation. To maximize the fit between farmers' needs and sustainable innovation, such an approach should be based on the co-creation of tailor-made and customized innovative communication solutions to better support the transition toward a more sustainable farming paradigm.

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Drivers of Innovation Adoption for Sustainable Agriculture

810 Table 1. *Main Socio Demographic Characteristics of the Participants.*

Variable	Levels	*n*	%	*M*	*SD*
Gender	Male	199	100		
	Female	0	0		
Occupation	Farmer	108	54.82		
	Farmworker	18	9.14		
	Contractor[a]	3	1.52		
	Other[b]	70	34.52		
Education	Elementary school	5	2.54		
	Middle school	68	34.52		
	High school	108	53.80		
	University degree	18	9.14		
Farm size	Up to 2 ha	28	14.74		
	From 2 to 9 ha	58	25.79		
	From 10 to 29	51	26.84		
	From 30 to 49	32	16.84		
	50 and over	30	15.79		
Age				38.46	16.92
Years of work experience in agriculture				17.60	15.75

[a] Someone who is temporally hired jointly with a specific equipment to perform work at a certain price or within a certain time.

[b] Includes the so-called 'part-time' farmers, those who do not have an official role in the agricultural industry but, in addition to their main occupation, spend time working in agriculture and using agricultural machinery (Singh & Williamson, 1981).

Table 2. *Descriptive Statistics for the Variables Investigated and Bivariate Correlations between Them.*

	Mean	*SD*	1	2	3	4	5	6	7
1. Personal-informal information (source: Rogers, 2010)	2.17	.98	1	.40***	.12	-.10	.02	.10	.13
2. Personal-formal information (source: Rogers, 2010)	1.20	.87		1	.20**	-.06	.12	.14	.18*
3. Impersonal information (source:Rogers, 2010)	1.64	.79			1	-.13	.05	.05	.01
4. Attitude toward adoption (source: Adrian, Norwood, & Mask, 2005)	2.86	.71				1	.12	.52***	.29***
5. Subjective norm (source: Lioutas & Charatsari, 2017)	1.86	.58					1	.10	-.03
6. Perceived behavioral control (source: Lioutas & Charatsari, 2017)	2.97	.79						1	.29***
7. Adoption (source: McDonald & Alpert, 2001)	2.40	.97							1

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

Table 3. *Structural Invariance of the Final Model across Type of Sustainable Measure*

	χ^2	*IFI*	*CFI*	*RMSEA* (90% *CI*)	χ^2 difference
B model	$\chi^2(8) = 10.70$, $p = .22$	.97	.97	.04 (.00, .10)	
I model	$\chi^2(13) = 13.72$, $p = .39$	.99	.99	.02 (.00, .07)	$\chi^2(5) = 3.02$, $p = .70$

Figure captions.

Figure 1. Prediction of Participants' Intention to Adopt Sustainable Agri-Environmental Innovations as a Function of Sources of Information Exposure and Social-Psychological Variables.

Appendix 1. The questionnaire we used in the study.

MEASURES FOR SUSTAINABLE AGRICULTURE: TELL US WHAT YOU THINK!

We are conducting a survey on the diffusion of practices and technologies for sustainable agriculture on farms. Thinking about the different types of strategies that are proposed to you, select the picture on each statement that best represents your thoughts.

Among the following the strategies for agricultural sustainability, please choose the one you had already experienced or used or had heard about:

- ☐ Rational use of water water *(e.g., drip irrigation)*
- ☐ Use of organic fertilizers *(burying of crop residues, green manure, compost)*
- ☐ Conservation tillage *(minimum/zero tillage, crop rotation)*
- ☐ Systems for diesel engine exhaust gas emission abatement *(urea-water solution – SCR, particulate filter – DPF)*
- ☐ Sensors and apps for farm management (*humidity sensors, temperature sensors, smartphone apps)*
- ☐ Precision agriculture *(driver assistance system, variable rate treatments)*

Thinking about the strategy you have chosen, please tell us whether you use it or intend to use it in your farm:

	I have already adopted it in my farm	I do not use it, but I am planning to adopt it	I do not use it, but I may adopt it in the future	I do not use it and do not intend to adopt it
Rational use of water *(e.g., drip irrigation)*	☐	☐	☐	☐
Use of organic fertilizers *(burying of crop residues, green manure, compost)*	☐	☐	☐	☐
Conservation tillage *(minimum/zero tillage, crop rotation)*	☐	☐	☐	☐
Systems for diesel engine exhaust gas emission abatement *(urea-water solution – SCR, particulate filter – DPF)*	☐	☐	☐	☐
Sensors and apps for farm management (*humidity sensors,*	☐	☐	☐	☐

temperature sensors, smartphone apps)				
Precision agriculture *(driver assistance system, variable rate treatments)*	☐	☐	☐	☐

Thinking about the strategy you have chosen, answer the following questions:

How much do you agree with the following statements about the chosen measure?

	I not at all agree			I completely agree
Adopting this measure is useful for farm operations	**1**	**2**	**3**	**4**
Adopting this measure is beneficial for farm operations	**1**	**2**	**3**	**4**
Adopting this measure is stressful	**1**	**2**	**3**	**4**

How true are for you the following statements on the possible reasons to adopt the measure?

	not at all true			completely true
Being motivated by my friends	**1**	**2**	**3**	**4**
Because people around me adopted it	**1**	**2**	**3**	**4**
I had the expertise needed to apply it	**1**	**2**	**3**	**4**
I want to keep up with the new trends within my community	**1**	**2**	**3**	**4**
I thought it would be easy to deal with it	**1**	**2**	**3**	**4**
I want to enjoy the appreciation of my peers	**1**	**2**	**3**	**4**
I did not want to be the last to adopt it	**1**	**2**	**3**	**4**

How often did you use the following sources to inform you about this measure?

	Never	***Rarely***	***Sometimes***	***Often***
Exhibitions	☐	☐	☐	☐
Journals/advertisements/internet	☐	☐	☐	☐
Discussions with peers/relatives	☐	☐	☐	☐
Discussion with consultants/trade organizations	☐	☐	☐	☐
Training courses	☐	☐	☐	☐

SOCIO-DEMOGRAPHIC INFORMATION

Gender: ☐ Male ☐ Female

Age: ________________

Education:

☐ None ☐ Middle school diploma ☐ Bachelor/Master Degree

☐ Elementary school diploma ☐ High school diploma ☐ Post-graduate

Profession:

☐ Farmer ☐ Contractor

☐ Farmworker ☐ Other____________________________

Years of work experience in agriculture _________________

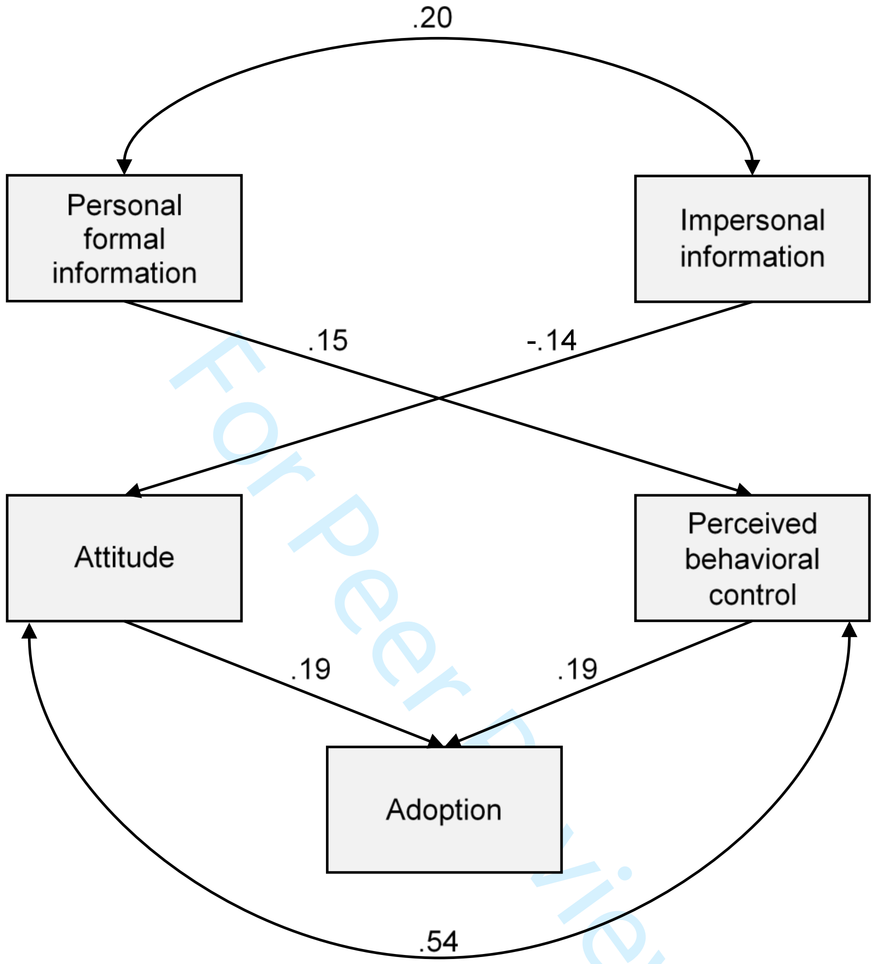
Farm size (ha):

☐ Up to 2 ☐ From 30 to 49

☐ From 2 to 9 ☐ 50 and over

☐ From 10 to 29

Figure 1.


.20
Personal formal information
Impersonal information
.15
-.14
Attitude
Perceived behavioral control
.19
.19
Adoption
.54