An ergonomic approach to sustainable development: The role of information environment and social-psychological variables in the adoption of agri-environmental innovations.

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An Ergonomic Approach to Sustainable Development: The Role of Information Environment and Social-Psychological Variables in the Adoption of Agri-Environmental Innovations

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16   **Abstract**

17   Sustainability is defined as meeting the human needs of current as well as future

18   generations. This anthropocentric perspective leads to joint objectives between

19   sustainability and ergonomics. In the present study, we adopted a systems ergonomic

20   approach and, based on the Theory of Planned Behavior, we analyzed the paths by which

21   the information environment can affect farmers' adoption of sustainable measures through

22   the mediation of attitudes, social pressure, and behavioral control. One hundred ninety-

23   nine Italian farmers completed a questionnaire assessing exposure to impersonal, personal-

24   formal, and personal-informal sources of information on the one hand and attitudes,

25   perceived behavioral control, and subjective norms toward the adoption of two types of

26   sustainable innovations (technological solutions and organizational/managerial practices)

27   on the other. The results showed that attitudes and perceived behavioral control were the

28   dominant determinants of farmers' adoption behavior, and personal-formal sources of

29   information were positively associated with perceived behavioral control. Possible

30   interventions are discussed for farmers' information environment to promote the adoption

31   of sustainable innovations.

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33   *Keywords:* Innovation adoption; Systems ergonomics; Sustainable agriculture;

34   Theory of Planned Behavior; Italy.

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37   **Introduction**

38   For most of human history (and prehistory), the size of the world population was

39   small enough that humans did not suffer from a significant loss of resources, since they

40   could relocate or resources could naturally regenerate. However, as the human population

41   grew, the pressures on resources increased, and the problem of sustainability arose

42   (Thatcher & Yeow, 2016). Sustainability is mainly an issue of resource scarcity or damage,

43   either at present or at some time in the future (Dekker, Hancock, & Wilkin, 2013).

44   Sustainable development has been defined by Brundtland's World Commission on

45   Environment and Development (World Commission on Environment and Development,

46   1987) as "development that meets the needs of the present without compromising the

47   ability of future generations to meet their own needs" (p. 41), and it is often

48   operationalized as a triple bottom line, maintaining the balance among the three pillars of

49   economic, environmental, and social capital, to achieve development that is sustainable

50   over a significant period of time (Lange-Morales, Thatcher, & García-Acosta, 2014).

51   Policymakers have integrated sustainability principles into regulations governing

52   agricultural systems. In 1990, the US Congress promulgated the Farm Bill, which applied

53   the concept of sustainability to the agricultural sector, defining agricultural sustainability

54   as an "integrated system of plant and animal production practices having a site specific

55   application that will, over the long term: (a) satisfy human food and fiber needs; (b)

56   enhance environmental quality; (c) make efficient use of non-renewable resources and on-

57   farm resources and integrate appropriate natural biological cycles and controls; (d) sustain

58   the economic viability of farm operations; and (e) enhance the quality of life for farmers

59   and society as a whole" (Public Law 101−624, Title XVI, Subtitle A, Section 1603, Senate

60   and House of Representatives of the United States of America, 1990). Since 1992, the

61   European Union has progressively integrated the sustainability principles in the Common

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62   Agricultural Policy, moving from price and production support to a policy of direct income

63   aid and rural development measures, including the so-called 'agri-environment measures',

64   to encourage more rational land use and protection of the environment, with the aims of

65   ensuring the delivery of environmental services, preserving the natural space and

66   landscape, and preventing the abandonment of agricultural land (European Union, 2008).

67   Agri-environment commitment can be pursued through the adoption of both

68   technological solutions and organizational/managerial practices (Lioutas & Charatsari,

69   2017). Technological solutions include all innovative technologies (e.g., farm equipment

70   and irrigation technologies) that can be merged into the production process.

71   Organizational/managerial practices refer either to changes in the organizational structure

72   of a farm enterprise or to the application of new ideas, methods, and techniques in the way

73   farming is practiced (e.g. the reuse of agricultural waste). Both of these types of measures

74   have the potential to deliver more sustainable agricultural production and to boost

75   agricultural productivity, based on a more precise and resource-efficient approach, thus

76   representing a new lever to enhance common or growing trends in agricultural

77   exploitations, such as family and organic farming (Knickel, Ashkenazy, Chebach, &

78   Parrot, 2017). Therefore, fostering the adoption of these measures is considered a key

79   element of the transition toward sustainable development by both policymakers and the

80   business sector (Schaltegger, Etxeberria, & Ortas, 2017).

81   Despite their relevance, the uptake of these measures is still sporadic, and knowledge

82   of the triggers of their adoption is underdeveloped (Burton, 2004a; Unay Gailhard,

83   Bavorová, & Pirscher, 2015). At present, the literature has mainly focused on economic

84   variables. According to a meta-analysis by Baumgart-Getz, Prokopy, and Floress (2012),

85   investment is the best predictor of the adoption of sustainable practices. Somewhat

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86   consistently, according to Long, Blok, and Coninx (2016), costs hinder the adoption of

87   climate-smart agricultural innovations and technologies.

88   Although farmers certainly have an interest in maximizing profit, the cost-benefit

89   models cannot sufficiently capture the complexity of farmers' decision-making and

90   behaviors. Indeed, farmers sometimes do not adopt a sustainable measure even though the

91   economic evidence suggests they should and, vice versa, they adopt a sustainable measure

92   even when the economic prospects are not clear or favorable (Flett et al., 2004; Wauters,

93   Bielders, Poesen, Govers, & Mathijs, 2010). The failure of the models focused on

94   economic triggers led to an increase in the application of new approaches in agricultural

95   studies (Baumgart-Getz et al., 2012; Burton, 2004a), indicating the role played by social-

96   psychological constructs such as attitudes, values, and goals in farmers' decision making

97   (Unay Gailhard & Bojnec, 2016) and stressing the importance of considering these factors

98   together with economic, environmental, social, and technological factors to contribute to

99   the process of rural development (Chang et al., 2017; Jafry & O'Neill, 2000).

100   Ergonomics and its systems approach represent an effective perspective from which

101   to investigate these issues. Ergonomics is the scientific discipline that applies theory,

102   principles, data, and methods to evaluate and adapt the design of tasks, jobs, products, and

103   environments to make them compatible with the needs, abilities, and limitations of people

104   (see https://www.iea.cc/whats/index.html). To achieve this aim, a systems approach to

105   understanding the interactions among people and all the other elements (artifacts,

106   information, environments, or other people) within a defined context is adopted (ISO

107   9000:2015; Wilson, 2014). A fundamental issue in ergonomics is the evaluation of the

108   efficiency of the system, defined as the resources expended in relation to the accuracy and

109   completeness of goals achieved, which is one of the main components for the assessment

110   of the usability of systems, products, and services (ISO 9241-11: 2018). Sustainable

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111 development and ergonomics share the joint objective of promoting an efficient allocation

112 and use of resources, adopting a common anthropocentric perspective centered on human

113 needs and actions (Thatcher & Yeow, 2016). The systems ergonomic approach can also

114 provide a deeper understanding of the necessary behavioral changes required by societies

115 to become sustainable (Hanson, 2013). In recent years, the ergonomic approach has been

116 used fruitfully in the agricultural and forestry sectors, leading to significant improvement

117 in work practices and to a significant increase in productivity through the standardization

118 of agricultural equipment, machine design, and health and safety legislation (Baron, Estill,

119 Steege, & Lalich, 2001).

120   In the present study, a systems ergonomic approach was adopted to analyze the

121 relationships between social-psychological variables and the farmers' information

122 environment about sustainable innovations to determine the best predictors of the adoption

123 of technological solutions and practices for sustainable agriculture in a group of Italian

124 farmers. The approach builds on the social-psychological Theory of Planned Behavior

125 (TPB: see Ajzen, 1991) and the innovation diffusion theory (Rogers, 2010) to build and

126 empirically test a fully mediated model aimed at predicting farmers' adoption of

127 sustainable measures as a function of farmers' impersonal and personal (formal and

128 informal) sources of information, with the mediation of attitudes, subjective norms, and

129 perceived behavioral control. This analysis can suggest possible solutions in terms of

130 policies, user-centered design of training, and information activities to support and

131 promote the adoption of innovation for sustainable agriculture among the agricultural

132 population (Daberkow & McBride, 2003; Lu, Yao, & Yu, 2005).

133   In the following section, we develop the research framework on the TPB and the role

134 of different sources of information in innovation adoption. Then, the context of the study is

135 described. Subsequent sections describe the methods applied (questionnaire) and the

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136   outcome of the study. Finally, the results are discussed, and conclusions are derived in the

137   last two sections.

138   **Theoretical background**

139   Based on the increasing importance of the social-psychological perspective in the

140   investigation of the uptake of sustainable measures (Burton, 2004a), in the present study,

141   we performed our analysis by referring to the Theory of Planned Behavior (Ajzen, 1991),

142   which has been widely used to predict and explain a specific behavior. According to the

143   TPB, human action is guided by the degree to which the execution of the behavior is

144   positively or negatively evaluated (attitude), by the perceived social pressure to engage or

145   not to engage in the behavior (subjective norm), and by one's own perceived capability to

146   perform the behavior successfully (perceived behavioral control). Together, these

147   components lead to a positive or negative intention to perform the targeted behavior,

148   which, in turn, efficiently predicts the actual behavior.

149   In recent years, the TPB has been fruitfully adopted in sustainable agricultural

150   studies. Wauters et al. (2010) showed that farmers' attitudes predicted the adoption of soil

151   conservation practices in Belgium. Moreover, Menozzi, Fioravenzi, and Donati (2015)

152   found that attitudes positively affected farmers' intentions to implement eco-friendly

153   farming practices in Italy, whereas attitudes and perceived behavioral control predicted the

154   intention to adopt voluntary sustainability schemes. Finally, in their study of the adoption

155   of green innovations in Greece, Lioutas and Charatsari (2017) noted that subjective norms

156   did not affect the adoption decision.

157   However, in these studies, external factors influencing attitudes, subjective norms,

158   and perceived behavioral control have been underinvestigated. A relevant role could be

159   played by the potential users' exposure to different sources of information, in that this

160   variable has been shown to be a key factor in a wide range of decision-making situations

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161 (Rogers & Beal, 1958). Moreover, information asymmetry has been listed among the

162 barriers to the diffusion of technological innovations, both in agriculture and in other fields

163 (Long et al., 2016; Lu et al., 2005; Tabrizian, 2019).

164   Regarding innovation adoption, in the present study, we built on the innovation

165 diffusion theory developed by Rogers (2010) to investigate the role played by information

166 sources on farmers' adoption of sustainable measures. Moreover, based on the "Guidelines

167 for Collecting and Interpreting Innovation Data" of the European Community Survey

168 (Organisation for Economic Co-operation and Development [OECD], 2005), we

169 considered innovation the implementation of a relevantly improved product, process, or

170 method in business practices, productive organizations, or relations. Thus, consistent with

171 Genius and Pantzios (2014; see also Unay Gailhard et al., 2015), we considered

172 innovations to be not only technological developments, which are typically considered a

173 disruptive advancement in agriculture (Cavallo, Ferrari, & Coccia, 2015), but also agri-

174 environmental practices and strategies and organizational and managerial procedures,

175 which are innovative and can enhance the environmental sustainability of a production

176 activity (Biddoccu, Opsi, & Cavallo, 2014; Pulina et al., 2018).

177   According to Rogers (2010), the diffusion of innovation is the "process by which an

178 innovation is communicated through certain channels over time among the members of a

179 social system" (p. 46). Information is shared with potential users through two main

180 channels: one impersonal channel (i.e., without a direct face-to-face exchange, such as the

181 mass media) and one personal channel (i.e., communication contacts that involve a direct

182 face-to face exchange). Personal contacts can be further divided into informal contacts

183 with relatives and peers and formal contacts with institutionalized sources. Valente (1995)

184 defines the diffusion of innovation as a communication process in which an adopter

185 persuades those who have not yet adopted to adopt. Through the communication channels,

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186   potential users are at first exposed to an innovation, and if they are interested, they actively

187   seek related information. Then, the individual weighs the advantages/disadvantages of

188   using the innovation and decides whether to adopt or reject the innovation. Then, he/she

189   finalizes his/her decision to continue using the innovation.

190   The few studies referring to Rogers' (2010) constructs for the adoption of sustainable

191   measures in agriculture showed that impersonal communication is the major source of

192   knowledge about an innovation (Defrancesco, Gatto, Runge, & Trestini, 2008; McBride &

193   Daberkow, 2003), while personal contacts are more effective in forming and changing

194   attitudes toward a new idea and thus in influencing the decision to adopt or reject it

195   (McBride & Daberkow, 2003). In addition, personal contacts are more effective than the

196   impersonal channel in enhancing users' innovativeness and adoption behavior, since they

197   involve users in a more direct way, thus making it difficult to ignore the message (Unay

198   Gailhard et al., 2015).

199   Regarding formal and informal personal sources, contrasting results have been

200   reported. Some studies have shown that farmers who participate in formal organizations

201   are more inclined to adopt different types of innovations (Jallow, Awadh, Albaho, Devi, &

202   Thomas, 2017; Unay Gailhard, Bavorová, & Pirscher, 2012), whereas other research has

203   noted the higher efficacy of frequent informal contacts (Defrancesco et al., 2008; Polman

204   & Slangen, 2008). However, in these studies, the role of the information environment has

205   usually been analyzed through discrete choice (logit or probit) models, while only

206   mediated models allow the researcher to detect the reason for the association between the

207   independent and dependent variables.

208   **Hypotheses**

209   The research conducted by Rogers (2010) showed that innovation adoption starts

210   with diffusion through communication channels. Since the adoption behavior is one type of

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211 behavior and the TPB postulates three components that explain a behavior (Ajzen, 1991),

212 we tested the following hypotheses:

213   H1: Having received information will show a positive association with attitudes

214 toward adoption;

215   H2: Having received information will show a positive association with subjective

216 norms toward adoption; and

217   H3: Having received information will show a positive association with perceived

218 behavioral control over adoption.

219   Given the inconsistent results in the extant literature, we made no specific

220 hypotheses regarding the association between each different source of information and

221 attitudes, subjective norms and perceived behavioral control.

222   According to the TPB (Ajzen, 1991), people who have positive attitudes toward the

223 behavior, who think that there is normative support for it, and who perceive that they can

224 easily perform it should have strong intentions to perform the behavior. Accordingly, we

225 developed and tested the following hypotheses:

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

227   H5: Higher perceived behavioral control will show a positive association with

228 adoption; and

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

230 with adoption.

231   Considering the variety of sustainable measures listed in the literature (Lioutas &

232 Charatsari, 2017; Unay Gailhard et al., 2015; Wauters et al., 2010), the model parameters

233 were tested across two different types of sustainable measures: technological solutions and

234 organizational/managerial practices (Lioutas & Charatsari, 2017). This approach allowed

235 us to determine whether the decision-making process varies for the different investigated

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236   measures and to eventually note the critical variables to be addressed with targeted

237   interventions to promote farmers' adoption of each type of sustainable measure.

238   **Context of the study**

239   We investigated the abovementioned issues in a sample of Italian farmers. Europe is

240   a particularly relevant context to investigate the issues related to the adoption of

241   sustainable measures, since the environmental objectives have become increasingly

242   integrated into the EU's Common Agricultural Policy, leading to an augmented importance

243   of understanding and anticipating the response of individual actors to policy measures

244   integrating sustainable practices (Burton, 2004a; Defrancesco et al., 2008; Long et al.,

245   2016). Among the EU-28 countries, Italy has the second-largest agriculture, with a

246   turnover of more than EUR 55 billion in 2015 (Eurostat, 2016). Italian farmers are

247   generally not deeply oriented toward environmental protection and sustainability (Menozzi

248   et al., 2015). Within Italy, the Piedmont region (northwestern Italy) offers an apt

249   representation of the Italian farming system and rural population, since it includes

250   approximately 10% of the total Italian utilized agricultural area and over 61,000 out of the

251   1,620,884 Italian agricultural holdings operate in this region (Istituto Nazionale di

252   Economia Agraria [INEA], 2014).

                                Materials and methods

            Participants and setting

255   The study involved a sample of 199 male farmers. Table 1 summarizes their

256   characteristics. The participants were recruited among the visitors of the 37th National

257   Exhibition of Agricultural Mechanization in Savigliano, the largest agricultural machinery

258   exhibition in the Piedmont region. The 2018 edition of the show (March 15-18) was

259   attended by over 60,000 visitors, with an exhibition area of approximately 49,000 m^2. The

260   Savigliano Exhibition is a public event that mostly features equipment but also attracts

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261 people and families because of its recreational and entertaining activities. Agricultural

262 exhibitions play an important role in the life of Italian small country towns, where they

263 often combine amusement elements, breeding stock exhibitions and sports happenings,

264 with lectures, seminars and conferences. These features make this kind of agricultural

265 exhibitions a suitable place for survey and data collection (Caffaro, Micheletti Cremasco,

266 Roccato, & Cavallo, 2018a; Cavallo, Görücü, & Murphy, 2015; Ferrari, Spinelli, Cavallo,

267 & Magagnotti, 2012; Reichardt, Jürgens, Klöble, Hüter, & Moser, 2009; Reichardt &

268 Jürgens, 2009).

269 **Instrument**

270 Participants were administered a 21-item paper-and-pencil questionnaire (see

271 Appendix 1) that was pilot-tested before use. The questionnaire was composed of 4

272 sections. In the first section, participants had to choose from a list of six sustainable

273 measures the one that they had already experienced or used or had heard about. The six

274 measures represented two types of innovations: technological improvements (sensors and

275 apps, systems for precision agriculture, and systems for diesel engine exhaust gas emission

276 abatement) and organizational/managerial practices (use of organic fertilizers, conservation

277 tillage, and rational use of water). These six measures were chosen to represent the

278 different types of sustainable innovations described by Lioutas and Charatsari (2017), and

279 they emerged as the most frequently cited measures in previous studies regarding

280 agricultural sustainability in different European countries (Lioutas & Charatsari, 2017;

281 Unay Gailhard et al., 2015; Wauters et al., 2010).

282 After this choice, the participants were asked to indicate whether they actually used

283 or intended to use the measure they had chosen on a 4-point rating scale based on

284 McDonald and Alpert (2001) (0: I do not use it and do not intend to adopt it; 1: I do not use

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285 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

286 already adopted it in my farm).

287 In the second section of the questionnaire, building on Adrian, Norwood, and Mask

288 (2005) and on Ajzen (2002), participants had to report on a 4-point scale (ranging from 1: I

289 not at all agree to 4: I completely agree) their agreement with the following 3 statements

290 regarding their attitude toward the chosen measure: adopting this measure is useful for

291 farm operations, adopting this measure is beneficial for farm operations, and adopting this

292 measure is stressful. These items were designed to represent both the instrumental and

293 experiential components of the overall attitude toward a behavior (Ajzen, 2002).

294 In the third section, subjective norms and perceived behavioral control (Ajzen, 2002)

295 were measured. Based on the scales developed by Lioutas and Charatsari (2017), the

296 participants had to indicate on a 4-point scale (from 1: not at all true to 4: completely true)

297 how true they considered the following statements about the possible reasons to adopt the

298 chosen measure: being motivated by my friends, because people around me adopted it, I

299 want to keep up with the new trends within my community, I want to enjoy the

300 appreciation of my peers, I did not want to be the last to adopt it, I had the expertise needed

301 to apply it, and I thought it would be easy to deal with it.

302 In the fourth section, the participants had to indicate on a 4-point scale (1: never, 4:

303 often) how often they were exposed to the following different sources of information about

304 the chosen measure: exhibitions, journals/advertisements/internet, training courses,

305 discussions with peers/relatives, and discussions with consultants/trade organizations.

306 These sources of information were selected based on those emerging from the literature

307 and previous studies as the most recurrent sources of information about innovation among

308 farmers (Rogers & Beal, 1958; Unay Gailhard et al., 2012). Based on Rogers and Beal

309 (1958), we expected the following factorial structure of the battery: discussions with

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310   peers/relatives to load on one factor (i.e., 'personal-informal'); training courses,

311   discussions with consultants/trade organizations to load on another factor (i.e., 'personal-

312   formal'); and journals/advertisements/internet and exhibitions to load on another factor

313   (i.e., 'impersonal').

314   A standard sociodemographic form that assessed participants' work-related

315   characteristics (profession, years of experience in the agricultural sector and farm size)

316   ended the questionnaire.

317   **Procedure**

318   Trained research assistants provided the questionnaire to exhibition attendees. The

319   assistants explained the aims of the study and informed the participants that the

320   questionnaire was anonymous. The questionnaire was in Italian, and its completion took

321   approximately 5-6 minutes. No incentive was offered to participate in the survey. The

322   response rate was approximately 90%.

323   **Data analysis**

324   We tested our hypotheses via a series of path analyses and utilized Amos 20

325   (Arbuckle, 2014). Path analysis is an extension of multiple regression that is particularly

326   effective in the pursuit of our goals for reasons that are twofold. First, path analysis allows

327   us to test mediated models, i.e., models in which some variables (in our case, the sources

328   of information) are postulated as causes, other variables are postulated as effects (in our

329   case, the adoption of agri-environmental sustainable innovations), and still other variables

330   are postulated as mediators, i.e., as effects of the former and causes of the latter (in our

331   case, the attitudes toward the adoption, the subjective norms about the adoption, and the

332   perceived behavioral control over the adoption). Second, path analysis allows for the

333   testing of the fit of the model to the data, giving the researcher much richer diagnostic

334   information on the model than that available in the multiple regression approach. We

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335   estimated our models using the maximum likelihood estimate, which facilitates the

336   identification of the parameters that maximize the likelihood function linking the model to

337   the observations.

338   We considered parameters with an associated *p* value < .05 to be significant. The fit

339   of the model was tested by combining different indices: the incremental fit index (*IFI*;

340   Bollen, 1990); the comparative fit index (*CFI*; Bentler, 1990); and the root mean square

341   error of approximation (*RMSEA*; Steiger, 1990). Based on the guidelines proposed by

342   Bentler (1990), we considered the *IFI* and the *CFI* to be satisfactory if they were higher

343   than .90. The *RMSEA* was considered satisfactory if it was lower than .05 and acceptable if

344   it was lower than .08. With the exception of the tests of structural invariance (see below),

345   when evaluating the overall fit of the model, we did not take into consideration the χ^2,

346   since its significance depends on the sample size.

347   Moreover, we tested the structural invariance of the model across the two types of

348   sustainable measures we analyzed. As suggested by Reise, Widaman, and Pugh (1993), we

349   first tested the fit of a *baseline model*, in which the model was tested simultaneously in the

350   participants who answered the questionnaire making reference to technological solutions

351   (sensors/apps, precision agriculture, and emission abatement) and in those who answered

352   the questionnaire making reference to organizational/managerial practices (use of organic

353   matter, conservation tillage, and rational use of water). Subsequently, we tested the fit of

354   an *invariant model*, in which all the parameters were constrained to be equal across the two

355   groups of sustainable measures. The model was considered invariant if the difference in

356   the χ^2 of the invariant model and of the baseline model did not reach statistical significance

357   for a number of degrees of freedom (DF) equal to the difference in DF of the two models.

358   In this case, we could indeed conclude that constraining the model's parameters to be equal

359   across the two groups of participants did not lead to a significant worsening in the model's

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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.

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 ps <

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).

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385　The model explained approximately 11% of the variance of the dependent variable ($R^2 =$

386　.11). Figure 1 shows the parameters we analyzed.

387　　Table 3 shows that our final model's parameters were invariant across the type of

388　sustainable measures (technological solutions and organizational/managerial aspects).

Discussion

390　In this study, we adopted a human-centered systems ergonomics perspective to investigate

391　the drivers of the adoption of sustainable measures in a sample of Italian farmers. Although

392　the explicit reference to the concept of sustainable development is relatively new in

393　ergonomics, the underlying ideas and approaches are not, particularly the systems

394　approach (Thatcher & Yeow, 2016). Indeed, the identification and visualization of links

395　and relationships between the different human-technical components of the system may

396　support the management of drivers and indicators that precede key social and

397　environmental impacts (Schaltegger et al., 2017).

398　　In particular, we analyzed the effects of the interaction between subjective factors

399　considered in the TPB (Ajzen, 1991) and the exposure to different sources of information

400　considered in Rogers' theory about innovation diffusion (Rogers, 2010) to identify critical

401　paths and components that may benefit from user-centered interventions (ISO 9241-

402　11:2018) aimed at enhancing the adoption of sustainable innovations in farming.

403　　The results showed that exposure to impersonal and personal-formal information

404　sources was associated with attitudes toward adoption and perceived behavioral control,

405　which in turn were positively associated with the adoption of sustainable measures. In

406　particular, personal-formal contacts had a positive association with perceived behavioral

407　control, whereas impersonal information sources had a negative association with attitudes.

408　　More specifically, the positive association between exposure to formal personal

409　sources of information (e.g., farmers' associations and training courses) and the adoption

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410   of a sustainable measure is consistent with previous results by Unay Gailhard et al. (2015),

411   which showed that an effective diffusion of information on organic farming could be

412   expected among German farmers when they were approached by formal organizations.

413   This positive association also confirms McBride and Daberkow's (2003) evidence that

414   technical (or "how-to") information from sources including vendors and professional

415   consultants were the most important to the potential adopters of precision farming

416   technologies among US farmers.

417   This result could be interpreted by considering Roger's (2010) concepts of

418   homophily and heterophily and their role in innovation diffusion and adoption. Homophily

419   is the degree to which a pair of individuals who communicate are similar, whereas

420   heterophily is the degree to which pairs of individuals who interact are different in certain

421   attributes. In the diffusion of innovation, the participants are usually quite heterophilous (a

422   consultant, for instance, is more technically competent than his/her clients), and this

423   information asymmetry (Tabrizian, 2019) frequently leads to ineffective communication

424   because the two individuals do not speak the same language. However, when two

425   individuals are identical regarding their technical grasp of an innovation, diffusion cannot

426   occur, as there is no new information to exchange. Thus, the nature of diffusion demands

427   that at least some degree of heterophily be present between the two participants in the

428   communication process (Rogers, 2010). Formal communication in our sample appeared to

429   be successful in helping individuals overcome informational asymmetry, since it enhanced

430   our participants' perceived behavioral control of the innovation, fostering further

431   investigations on how the information is provided to potential users, i.e., the key messages

432   conveyed and the media through which they are disseminated.

433   The significant effect of perceived behavioral control on innovation adoption is

434   consistent with that stemming from the study by Fielding, Terry, Masser, and Hogg (2008),

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435 which found that perceived behavioral control was a significant predictor of the intention

436 to engage in riparian zone management among Australian farmers. As noted by Rogers

437 (1976), the topic of control is strictly interwoven with the concept of development, which

438 can be defined as "a widely participatory process of social change in a society intended to

439 bring about both social and material advancement (including greater equality, freedom, and

440 other valued qualities) for the majority of people through their gaining greater control over

441 their environment" (p.224). Enabling farmers to perceive the adoption of innovative

442 farming measures as being under one's own volitional control appeared in our study to be a

443 key concept promoting sustainable development in agriculture, and it shall be pursued

444 through user-centered institutionalized communication activities built on the limits and

445 capabilities of the potential users (Agbedahin, 2019). Similar to the proposal of Hickman,

446 Rogers, and Fisk (2007) regarding training on a hydroponic garden control system, some

447 practical training could also be proposed, with periodic refreshes when technological

448 upgrades are released or new practices are introduced.

449   Based on the present results, personal sources of information may have a substantial

450 capacity to influence farmers' decision-making about the adoption of sustainable measures,

451 highlighting the need to involve farmers' associations and consultants in the organization

452 of informative events and focused training activities to provide farmers with the skills

453 needed to address different practices and innovations. Education has been acknowledged

454 as the most powerful transformative force in the achievement of a sustainable future

455 (Hopkins & McKeown, 2001). Education requires a participatory approach in teaching and

456 in the development of training methods (Caffaro, Micheletti Cremasco, Bagagiolo,

457 Vigoroso, & Cavallo, 2018b) to motivate and empower both apprentices and teachers to

458 learn, reflect, change their behavior, and take action for sustainable development. The

459 participation of stakeholders is deeply rooted in the vision of sustainable development as a

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460   collaborative process of involving stakeholders to initiate and diffuse the technical,

461   organizational, and social innovations necessary for greater sustainable development, with

462   regard to environmental, social, and economic aspects (Moss & Fichter, 2003).

463   On the other hand, the results of the study showed that impersonal sources of

464   information (e.g., exhibitions, internet, and advertisements) affect the adoption of a

465   sustainable measure through a negative association with attitude. The role played by

466   attitude is consistent with those identified in previous studies applying the TPB to the

467   agricultural domain, in which farmers' attitudes consistently emerged as an important

468   predictor of the adoption of soil erosion control practices in Belgium (Wauters et al.,

469   2010), riparian zone management in Australia (Fielding et al., 2008), and climate

470   information use and water conservation activities in Iran (Sharifzadeh, Zamani, Khalili, &

471   Karami, 2012; Yazdanpanah, Hayati, Hochrainer-Stigler, & Zamani, 2014). The present

472   result highlighted the importance of understanding farmers' attitudes to effectively

473   promote the adoption of sustainable innovations. Further insights into the critical factors in

474   the development of attitudes will be necessary to design policy measures that can alter

475   farmers' attitudes and thus promote engagement in sustainable practices.

476   Innovatively, compared to the existing literature, impersonal sources of information

477   showed a negative association with attitudes. Information disseminated by the mass media

478   is usually the most common channel through which farmers are made aware of the

479   existence of an innovation (McBride & Daberkow, 2003). Ineffective communication at

480   this level can lead to a lack of awareness, resulting in failed diffusion and lower rates of

481   adoption (Rogers, 2010). Based on the present results, it is possible that current traditional

482   argument-based communication campaigns should be reconsidered, and tailored

483   communication approaches that take different farmers' attitudes into account could be

484   recommended (Jansen, Renes, & Lam, 2010). As suggested by Menozzi et al. (2015), a

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485   peripheral route of communication using implicit persuasion techniques (Jansen et al.,

486   2010), which is recommended when farmers are less motivated to perform the desired

487   behavior, could also be appropriate.

488   Personal-informal sources of information did not show any significant relationships

489   with attitudes, subjective norms, perceived behavioral control, and the adoption of a

490   sustainable measure. Similarly, subjective norms did not show any association with

491   adoption. At first glance, the lack of association between personal-informal sources of

492   information and the dependent variable could appear somewhat surprising, since the

493   literature showed that interpersonal informal networks comprising friends and colleagues

494   represent an important source of information (Unay Gailhard et al., 2012, 2015). On the

495   other hand, the result regarding subjective norms is consistent with the evidence of the

496   meta-analytic review about TPB (Armitage & Conner, 2001), which noted that subjective

497   norms were the weakest predictor of actual behavior, as well as with the results of previous

498   studies applying the constructs of TPB to the agricultural sector (Lioutas & Charatsari,

499   2017; Menozzi et al., 2015; Wauters et al., 2010). The nonsignificant effects of informal

500   communication and subjective norms could be interpreted by considering that farmers

501   attribute high importance to independence (Caffaro et al., 2018c; Sullivan, 1996) and often

502   perceive themselves as uninfluenced by neighboring farmers' opinions and behaviors

503   (Burton, 2004a, 2004b). This evidence may suggest that key stakeholders in sustainability

504   promotion (e.g., public authorities) should improve the involvement of farmers in

505   exchanging information and sharing the benefits of implementing sustainable measures.

506   On a related note, our model was invariant across the two different types of

507   sustainable measures considered. Further investigations that widen the range of sustainable

508   measures surveyed could be interesting. At present, however, based on our results,

509   sustainable measures diffusion appears to be a general process that displays patterns and

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510 regularities that are not bound by the type of innovation studied (Rogers, 2004). Thus, we

511 provisionally conclude that communication interventions aimed at widening the adoption

512 of sustainable measures do not need to be tailored to the characteristics of the specific

513 measure one aims to promote.

Limitations of the study and future research developments

515 Some limitations of the present study should be acknowledged. First, the participants

516 were farmers only from the Piedmont region and were not chosen via a random sampling

517 procedure. However, the suboptimal representativeness of our sample could be less

518 problematic than it may appear at first glance for reasons that are twofold. First, previous

519 studies have shown that farmers from Piedmont can be usefully surveyed to analyze the

520 dynamics of the Italian farming population (Caffaro et al., 2018b). Second, we were

521 interested in studying the relations between variables in at least bivariate analyses and not

522 their absolute state as resulting from univariate analyses. In these cases, the bias stemming

523 from the lack of complete representativeness of the sample is significantly less impacting

524 (Roccato, 2008). Moreover, participants were selected among the visitors of an agricultural

525 exhibition. Generally, according to the literature on social capital theory, one could expect

526 that our sample was probably composed of farmers who are more open to innovative/new

527 ideas relative to nonparticipants (Polman & Slangen, 2008). If this were true, our sampling

528 process could lead to a selection bias. However, due to the very peculiar characteristics of

529 the Savigliano exhibition (which combines amusement elements with seminars and

530 conferences), we are confident that participants involved in the study nicely represent

531 Italian farmers. Thus, as a whole, we are confident about the validity of our results.

532 However, new research performed in additional regions of Italy and in other countries to

533 obtain more generalizable results would be welcome.

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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.

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

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559   technological or organizational/managerial, Lioutas & Charatsari, 2017), it would be useful

560   to adopt multidimensional measurements and a systems ergonomic approach focusing on

561   the skills needed to empower farmers and enhance their perceived control of the

562   innovation. In addition, information campaigns could be developed adopting a bottom-up

563   participatory approach to the diffusion of innovation. To maximize the fit between

564   farmers' needs and sustainable innovation, such an approach should be based on the co-

565   creation of tailor-made and customized innovative communication solutions to better

566   support the transition toward a more sustainable farming paradigm.

567   **Competing interests**: None to declare.

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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).

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812   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

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

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814   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)	$\chi^2(5) = 3.02, p = .70$

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817   Figure captions.

818   *Figure 1.* Prediction of Participants' Intention to Adopt Sustainable Agri-Environmental

819   Innovations as a Function of Sources of Information Exposure and Social-Psychological

820   Variables.

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822   Appendix 1. The questionnaire we used in the study.

MEASURES FOR SUSTAINABLE AGRICULTURE: TELL US WHAT YOU THINK!

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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.

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827
828
829

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)*

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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,*	☐	☐	☐	☐

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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	☐	☐	☐	☐

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837 **SOCIO-DEMOGRAPHIC INFORMATION**

838 **Gender:** ☐ Male ☐ Female

839 **Age:** _____

840 **Education:**

☐ None ☐ Middle school diploma ☐ Bachelor/Master Degree

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

841 **Profession:**

☐ Farmer ☐ Contractor

☐ Farmworker ☐ Other_____

842 **Years of work experience in agriculture** _____

843 **Farm size (ha):**

☐ Up to 2 ☐ From 30 to 49

☐ From 2 to 9 ☐ 50 and over

☐ From 10 to 29

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Figure 1.