**Strategic management implications for the adoption of technological innovations in agricultural tractor: the role of scale factors and environmental attitude**



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# Strategic management implications for the adoption of technological innovations in agricultural tractor: the role of scale factors and environmental attitude

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Technological innovations in agricultural tractors have revolutionised farming, increased labour productivity and reduced operator's hazards. The purpose of this paper is to analyse the relation between agricultural tractors' technological innovations and farm size, as well as users' attitude on environmental impact of agricultural tractors according to their age and years of activity in the farm. Results, concerning Italy, highlight that high technological innovations of tractors are associated to larger farms, which are managed professionally by more efficient and sophisticated agricultural machineries. Empirical evidence also shows that the older the tractor adopters are and the longer they have been working in agriculture, the higher is their commitment to environment protection and safe working conditions. These results could be important for critical strategic management implications to spur technological innovation in agricultural tractors that better satisfy farmer's needs and to support the fruitful adoption of innovations for an efficient and safe modern agriculture.

**Keywords:** agricultural tractor; scale factor; learning; technological innovation; technological trajectories; adopters; farmers; strategic management.

## 1. Introduction

Agriculture is an area with significant application of high technology and, during the last century, exceptional advances in engineering knowledge have revolutionised farming (Sassenrath et al 2008). In fact, diffusion of technological innovation by agricultural machines, a vital technological paradigm,[1] has received much attention by economics of technical change since 1960s because it tends to increase the productivity and to generate more social surplus (Rogers 1995; Korsching 2001; Ball and Norton 2002; Wright 2012). The Hicksian concept of induced innovation[2] has been the

most important topic of analysis by economics in agriculture (Possas, Salles-Filho and Da Silveira 1996; Sahal 1981a,b; Coombs, Gibbons and Gardiner 1981; Coccia, 2004, 2005a,b). Agricultural tractors have to cope with complex working conditions and play a vital role in farm operations (Tanelli et al. 2011). They remain the most important machine on the farm and for the agricultural market (Day, Field and Jarvis 2009; Iftikhar and Pedersen 2011; Singh and Singh 2011; Glenna, Jussaume and Dawson 2011; Aubert, Schroeder and Grimaudo 2012). The demand for agricultural machinery is strongly dependent on a farm's income, which is influenced by exogenous variables (e.g. agricultural policy, socio-economic environment, people attitude, climate conditions and public policies). In recent years, the European crisis (Coccia 2012) and structural changes in European agriculture have affected income and R&D investment behavior (Coccia 2009a), increasing the level of uncertainty and reducing farmers' propensity for new equipment investment with higher technological content (Vieweg 2012). An interesting problem for the economics of innovation and management of technology, in the agricultural industry, is to analyze the attitude of users towards the technological innovations adopted in agricultural tractors. Considering this context, the purpose of the paper is to answer
the following research questions:

(RQ1) *Does farm size structure affect the adoption of new technological innovations in agricultural tractors?*
(RQ2) *How does farmers'age affect their sensibility to environmental impact of agricultural tractors?*

In order to analyse these issues concerning structural change and dynamics of innovations of agricultural tractors in farms, the paper is laid out as follows: section 2 describes the theoretical framework of the study, whereas section 3 presents the hypotheses and research design; section 4 shows the empirical evidence and discusses the relationship between observed facts. Then concluding remarks are drawn.

## 2. Theoretical background

Current technological innovations in agricultural tractors are generating several technological trajectories to improve efficacy, efficiency and safety (Da Silveira 2002; Kemp, Schot and Hoogma 1998). These technological trajectories are, in general, driven by demand–pull and technology–push forces associated to learning processes (Dosi 1982, 1988; Nelson and Winter 1982; Consoli 2008). In particular, demand and technological opportunities can affect the direction of technological advance in agriculture. Teece (2008, 509, original emphasis) argues that: Technological paradigms impose behavioural structures associated with 'normal' problem-solving activity. Paradigms imply the use of established problem-solving routines; they indicate where to focus resources and help identify blind alleys to avoid. Nelson (2008) seeks to pinpoint the causes of fruitful scientific advances of technological paradigms in some fields in comparison with other fields that have scientific and technological infertility. Some determinants, according to Nelson (2008), are the economic and human resources invested to find a solution to 'relevant problems' (Dosi 1982, 1988), and to a lesser degree "'effective demand"' (Nelson 2008, 487). As a matter of fact, advancements in some technological pathways are easier than others and an intensive scientific research activity can support a faster progress of some technological paradigm, though 'relationships between the ability to advance *Strategic management implications for the adoption of technological innovations* 767 practical know-how and the strength of scientific knowledge underlying that know-how are complex' (Nelson 2008, 487). Technological trajectories also depend on other elements in addition to economic resource such as effective demand, institutional interest, needs of society and scientific research (Rosenberg 1983; Da Silveira 2002; Kemp, Schot and Hoogma 1998). Nelson (2008) claims that the evolutionary growth of knowledge and technology is also supported by a process of accumulation based on the ability to identify, control and replicate practices, in other words, the technological progress is based on 'a certain amount of the "routine"' (Nelson 2008, 488; Nelson andWinter 1982, *passim*). In general, the technology incorporated in a tractor has a considerable influence on tractors' production costs and on retailers' price. A global company, for example, sells the same basic concept of an 80–100 hp (horse power) tractor in India for US$150/hp, in China for US$250/hp and in Europe and North America for US$1400/hp. The remarkable difference is mainly due to the increasing complexity in safety, comfort and environmental technical solutions adopted (Von Pentz 2011).

The modern farm tractor has a design very similar to that of the self-propelled steam traction engine of the late nineteenth century (Sahal 1981a, 132). In the statement of Baker (1970, 32): 'the tractor has evolved around an essentially unchanged configuration. The only true innovation has been the three-point linkage and control system.'Patterns of technological innovations of agricultural tractor are based on minor and major innovations, as a consequence of an accumulation of design and production experiences over time. Nowadays, most of the technological innovations of agricultural tractors are due to improvement of safety and comfort for users and reduction of the environmental impact (*cf.* Coccia 2009b). For example, exhaust emissions from diesel engines fitted on agricultural tractors have a detrimental impact on human health and environment. In order to reduce these emissions, the European Union (1997) has, over time, introduced strict emission requirements requiring the adoption of catalytic converters or particle filters. Larsson and Hansson (2011) notice that some technological innovations, such as diesel oxidation catalyst (DOC)/diesel particulate filter (DPF) systems decrease the impact on human health, while selective catalytic reduction (SCR) catalytic converter decreases the acidification and eutrophication impact. In general, the adoption of agricultural tractors and associated technological innovation in agriculture have played a main role for increasing the productivity (Coccia 2008). Sahal (1981a) remarks that advances of technological innovations in agriculture can be driven by some characteristics of the farm system and organisation, rather than a change of the farming system in response to the technology. For instance, the garden tractor has been necessitated by the needs of very small farms (Sargen 1979). Baker (1970, 391) claims that: 'The future of tractors appears most vulnerable to new methods of land preparation, planting and cultivating'. In addition, Sahal (1981a, 137) argues that long-run development of tractor technology is likely to be driven by farm organisation and farm size structure and this one-way dependence of patterns of technological innovation could persist in the foreseeable future. To sum up, considering this theoretical framework, we proceed to analyse some vital epistemological positions concerning the adoption of technological innovations concerning agricultural tractor in farms.

## 3. Hypotheses and research design

The study here explores the role of scale factor and farmers' environmental attitude in relation to agricultural tractors innovations. The research questions, described above, can be used to design the two scientific hypotheses (*HPs*) that we are going to test:

(*HP1*) *Scale factor of agricultural tractor innovations*: agricultural tractor innovations are positively associated with larger farms.

(*HP2*) *Adopters' environmental learning*: agricultural tractor innovations that reduce environmental impact are positively associated with higher farmers' expertise.

The purpose of the present study is to see whether statistical evidence supports the hypotheses. The results can be important to understand the socio-economic conditions that support new technological trajectories in agricultural tractors as well as the determinants of the strategic change of farms.[3]

### *3.1. Study questionnaire*

A survey was carried out during the 37th edition of the most popular event in Italy in the field of machinery technologies for agriculture: the International Exhibition of Agricultural Machinery (EIMA). During the event over 300 questionnaires were filled up by owners and/or users of agricultural tractors, randomly selected among the people visiting the agricultural tractors pavilions. A computer-assisted personal interview was used to administer the questionnaire, designed using web-based survey software (www.surveymonkey.com). Data were collected on a group of mobile devices (*iPads*) and trained interviewers administered the questionnaire, assisting respondents if needed (Ferrari et al. 2013). The use of the *iPad* as a survey instrument has undoubtable advantages over traditional paper-and-pencil questionnaire and provided a new and engaging way to gather information (Greenlaw and Brown-Welty 2009). The questionnaire is a close-ended structured instrument, divided in 10 sections, containing both objective contents and attitudinal/opinion questions (subjective content). Table 1 shows the information included in the questionnaire: background data on the farm (*i.e.* farm size and number of tractors) and on the user, such as work type, years of work and age group (*objective content*). Other questions concern the opinions of farmers on what they consider important in tractor usage and what technological innovations are useful for (*subjective content*). Additionally, among a list of technological innovations available on the market (*see* Table 2), they were asked to express their opinions on the more useful innovations (*subjective content*), to list those they have and those they do not have on their tractors (*objective content*) and finally to report the innovations they wished their tractors were equipped with (*subjective content*). To gather the opinions farmers we apply a four-point Likert scale (very much, somewhat, a little, not at all).

### *3.2. Data analysis*

Data analysis has been conducted exclusively on subjects who affect directly the tractor market, being those who make the actual purchase of machines. The data set was cleaned by removing students, people working in the agriculture machinery trade or service sector and people whose primary work activity is not related to agricultural sector. As a result, 228 questionnaires, accounting for 75% of the total number, were analysed. Descriptive analysis was conducted with SPSS statistical software version 17 (SPSS 2007). In order to know the relationship between and among the variables investigated chi-square test ($\chi 2$) and Cramer's $V$ were calculated. While the $\chi 2$ value is affected by both the strength of the association between the two variables and the size of the sample, Cramer's $V$ removes the effect of the sample size, leaving a measure of the strength of the relationship between two variables. To investigate the direction of relationships, Spearman's rank correlation coefficient

Table 1. Questionnaire.

| Objective content | Subjective content | Objective content |
|---|---|---|
| (1) Farm size<br>☐ *< 5 ha*<br>☐ *5–20 ha*<br>☐ *> 20 ha*<br>(2) Number of tractors<br>☐ *1–3*<br>☐ *4–6*<br>☐ *7–9*<br>☐ *More than 9*<br>(3) Work type<br>☐ *Farmer*<br>☐ *Farm worker*<br>☐ *Independent contractors*<br>(4) Years of work<br>☐ *<3 years*<br>☐ *3–10 years*<br>☐ *> 10 years*<br>(5) Age group (*years old*)<br>☐ *18–25*<br>☐ *26–35*<br>☐ *36–45*<br>☐ *46–55*<br>☐ *>55* | (6) What is important in tractor usage?<br>☐ *Technological content*<br>☐ *Environmental impact*<br>☐ *Comfort*<br>☐ *Safety*<br>☐ *Ease of maintenance and assistance*<br>(7) Technological innovations are useful for:<br>☐ *Reducing costs*<br>☐ *Reducing environmental impact*<br>☐ *Increasing comfort*<br>☐ *Increasing safety*<br>☐ *Increasing reliability*<br>(8) Technological innovations more useful:<br>☐ *[CVT]* ☐ *[ISO]*<br>☐ *[GPS]* ☐ *[Speed]*<br>☐ *[NCfuel]* ☐ *[ABS]*<br>☐ *[POWER]* ☐ *[FLEET]*<br>☐ *[RD]* ☐ *[ELECT]*<br>(10) I wish the tractors I use were equipped with:<br>☐ *[CVT]* ☐ *[ISO]*<br>☐ *[GPS]* ☐ *[Speed]*<br>☐ *[NCfuel]* ☐ *[ABS]*<br>☐ *[POWER]* ☐ *[FLEET]*<br>☐ *[RD]* ☐ *[FLEET]* | (9) Technological innovations available on the tractors I use:<br>☐ *[CVT]*<br>☐ *[GPS]*<br>☐ *[NCfuel]*<br>☐ *[POWER]*<br>☐ *[RD]*<br>☐ *[ISO]*<br>☐ *[Speed]*<br>☐ *[ABS]*<br>☐ *[FLEET]*<br>☐ *[ELECT]* |

*Note:* CVT: Continuously variable transmission; GPS: Assisted guidance system; NCfuel: Alternative fuels; POWER: Overpower/Power-Boost; RD: Remote diagnostics system; ISO: ISOBUS/CAN-BUS; Speed: Speed greater than 40 km/h; ABS: Assisted braking systems; FLEET: Fleet management; ELECT: Electric actuators. ha = hectares. (*cf.* Ferrari et al., 2013).

($r_s$), a nonparametric measure of statistical dependence between two variables was calculated as well as for all variables representing ordinal measures. Additionally, a multiple correspondence analysis (MCA) was conducted using R software, applying FactoMineR (Escoffier and Pagès 1994) and CA (Nenadic and Greenacre 2007) packages. The percentage of explained variance of the first two factors was re-evaluated using the Benzecri (1973) method.

## 4. Empirical evidence and discussion

The analysis is applied considering a main case study: Italy. In 2008 Italian farms had about 1.75 million tractors (Unacoma 2008), placing Italy third in terms of international tractor fleets after USA and Japan (World Resources Institute 2012). Italy is a world leader in tractor production

*[CVT] Continuously variable transmission*
Tractors are equipped with mechanical transmissions that offer a fixed number of gear ratios. CVTs can change steplessly through an infinite number of effective gear ratios between minimum and maximum speeds. CVTs provide better fuel economy, enabling the engine to run at its most efficient revolutions per minute (RPM) for a range of vehicle speeds. Alternatively, CVTs can be used to maximise tractor's performance by allowing the engine to turn at the RPM at which it produces peak power making possible to improve productivity, work precision, energy efficiency, environment protection and driver comfort (Renius and Resch 2005). The most known CVT is the 'Vario' transmission developed by Fendt and produced since 1996. Its outstanding success motivated competitors to follow and design CVTs solution for their tractors.

*[GPS] Assisted guidance system*
In agricultural tasks, tractors usually need to follow a trajectory equidistant to a previous pass. This action can be easily accomplished when the tractor is equipped with an assisted global positioning system – GPS (Yao, Zhang and Minsan 2005), a guidance system that controls the tractor along a trajectory (Bell 2000). The system uses a combination of a positioning system, tractors' onboard sensors, a computer to process the information and mechanisms to control the trajectory, relieving the operator from many of the tasks involved in guiding a vehicle.

*[NCfuel] Alternative fuels*
Considerable attention has been paid to alternative renewable liquid fuels production (Hansen, Zhang and Lyne 2005). Biodiesel is the most relevant fuel for tractors because it does not require modifications in existing diesel engines (Patterson et al. 2006), can be used directly or as blends with diesel fuel (Demirbas 2009), and only a small decrease in performances is reported compared with mineral diesel (Bozbas 2008; Tomic et al. 2013). Biodiesel is derived from edible and inedible vegetable oil, animal fats, used frying oil and waste cooking oil. This fuel can contribute to reduce the global warming and environmental degradation.

*[POWER] Overpower/Power-boost*
It makes possible to deliver additional engine horsepower in specific working conditions, such as high-power PTO (power take-off) applications and road transport operations, improving the tractor's efficiency.

*[RD] Remote diagnostics system*
Recent advances in remote communications and embedded system technologies have led to share in-vehicle sensors and diagnostic information with remote computers, enabling remote vehicle diagnosis, communicating when maintenance is necessary (You, Krage and Jalics 2005).

*[ISO] ISOBUS/CAN-bus*
ISO 11783 (International Standards Organisation 2007) is a standard for electronics communications protocol for agricultural and forestry equipment based on controller area network (CAN) data bus developed by Bosch Company (Cox 2002). This standard has been developed to meet the needs for electronic communication among sensors, actuators, control elements, information-storage and display units embedded in tractors, implements, and other self-propelled agricultural machines. It supports precision farming applications, operator interfaces and communications with an off-board management information system. The system can be used to coordinate machine components, to allow information to be shared among components of a machine and to be distributed across components of a machine (Stone et al. 1999; Renius 2009).

*[Speed] Speed greater than 40 km/h*
Since 1994, responding to customers' demands to increase tractors' transport performance, manufacturers started to offer tractors with a maximum speed higher than 40 km/h. All major tractor manufacturers are now offering tractors at 50 km/h.

*[ABS] Assisted braking systems*
The assisted braking system gained great popularity in agricultural tractors. Compressed air and hydraulic brake systems are integral parts of the tractors or available as retrofitting components.

*[FLEET] Fleet Management*
Fleet Management is a tool commonly adopted in transport and construction business to improve fleet of vehicles operational measures (Sørensen and Bochtis 2010). Agriculture application of fleet management systems permits to have better timing of field work and co-ordination of available equipment, resulting in less traffic and number of trips, more adequate co-ordination of transport vehicles and site-specific accumulation of goods, machinery use and decrease in energy and labour costs (Auernhammer 2001).

*[ELECT] Electric actuators*
Current manufacturers present agricultural machines with electrical driven actuators: trailed sprayer from Amazone region, mechanical and pneumatical fertiliser spreaders and pneumatic seed drill from Rauch. The benefits are the optimised controllability and distribution of power flows across and between agricultural machines, real 'plug & play' for implements, increased flexibility in arrangement of components, enhanced productivity and operator comfort, and reduction of input costs (Buning 2010).

Table 3. Significant relationships between sample characteristics and questionnaire statements.

| No. | Sample characteristics Variable 1 | Questionnaire statements Variable 2 | $\chi^2$ | *df* | *p* | $r_s$ | *df* | *p* | Cramer's *V* |
|---|---|---|---|---|---|---|---|---|---|
| | *Important features in tractor usage* | | | | | | | | |
| 1 | Farm size | Comfort | 16.069 | 6 | 0.013 | 0.477 | 226 | 0.004 | 0.270 |
| 2 | Age | Environmental impact | 27.532 | 12 | 0.006 | 0.171 | 226 | 0.010 | 0.201 |
| 3 | Years of activity | Environmental impact | 23.015 | 6 | 0.001 | 0.225 | 226 | 0.001 | 0.225 |
| | *Useful features of technological innovations* | | | | | | | | |
| 4 | Years of activity | Increase safety | 14.774 | 6 | 0.001 | 0.222 | 226 | 0.001 | 0.180 |
| 5 | Years of activity | Increase reliability | 18.880 | 6 | 0.004 | 0.219 | 226 | 0.001 | 0.203 |
| 6 | Years of activity | Reduce environ. impact | 22.537 | 6 | 0.001 | 0.181 | 226 | 0.006 | 0.222 |
| | *Useful technological innovations* | | | | | | | | |
| 7 | Farm size | Assisted Guidance System | 15.961 | 8 | 0.043 | 0.176 | 218 | 0.009 | 0.190 |
| 8 | Farm size | CVT | 17.020 | 8 | 0.030 | 0.183 | 218 | 0.006 | 0.197 |
| 9 | Farm size | Overpower/Power Boost | 17.415 | 8 | 0.026 | 0.214 | 218 | 0.010 | 0.199 |
| 10 | Farm size | Remote diagnostics | 16.012 | 8 | 0.042 | 0.187 | 218 | 0.005 | 0.191 |
| 11 | Farm size | Alternative flues | 16.381 | 8 | 0.037 | −0.168 | 218 | 0.013 | 0.193 |
| 12 | No. of tractors owned | Remote diagnostics | 21.701 | 12 | 0.041 | 0.141 | 226 | 0.034 | 0.178 |
| 13 | No. of tractors owned | Fleet management system | 24.177 | 12 | 0.019 | 0.167 | 226 | 0.011 | 0.188 |

Source: Ferrari et al., 2013.

(Unacoma 2008) and its agricultural machinery manufacturing industry is made out of large globally active groups and small and specialised companies that are closer to their clients and better placed to know their needs (*cf.* Vieweg 2012). In general, large companies dominate the tractor market and roughly 80% of the vehicles are manufactured by 20% of the manufacturers – (Pareto principle, Vieweg 2012). In 2008 and 2009 the Italian agricultural tractor manufacturers assembled more than 27,000 vehicles. In 2011 this number decreased to 23,500 units, as a consequence of the global financial crisis (Coccia 2010; Federunacoma 2012). Approximately 1,729,000 farms are operative in Italy, utilising an area of 12.7 million hectares (ha)[4] (Istat 2005). Based on data of The National Institute for Statistics of Italy (*Istat*), 80% of farms are smaller than 5 hectares and their average size is 7.6 ha (Istat 2009). Moreover, Italy has a farm tractor density of approximately 138 every 1000 ha; this is higher than Germany (85.8), France (64.5) and the USA (26.8) (World Resources Institute 2012). More than 75% of the analysed sample is represented by farmers. Figure 1 and 2 show that the majority owns or works in a farm larger than 20 hectares and deals with a number of tractors between 4 and 6. Table 3 displays main results concerning the relation between variables.

*Test of HP1*

A significantly strong association is found between farm size and comfort, acknowledged for its importance in tractor usage; in the larger farms, more comfort in agricultural tractors is recognized as an important aspect (No. 1).

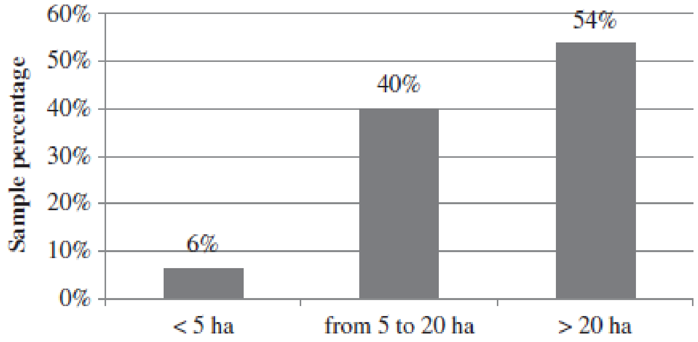


Figure 1. Farm size distribution in Italy.
Source: Ferrari et al., 2013.

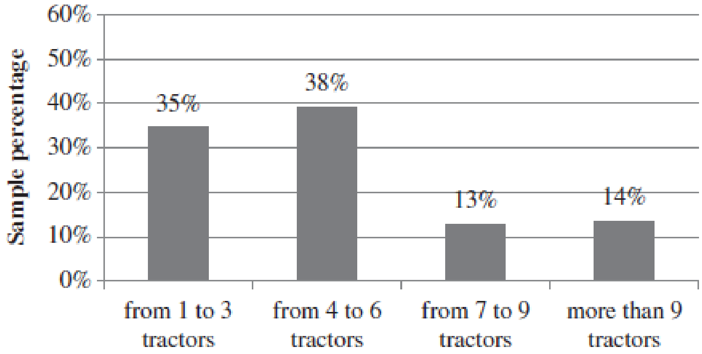


Figure 2. Distribution of the number of agricultural tractors owned or used.
Source: Ferrari et al., 2013.

Moreover, farm size has an association statistically significant with many technological innovations. In particular, the larger the farm is, the more useful the technological innovation is believed to be: assisted guidance system (No. 7), CVT (No. 8), overpower/power-boost (No. 9), and remote diagnostics system (No. 10). The only exception to this positive association is related to the opinions on alternative flues (No. 11). In contrast, remote diagnostics systems (No. 12) and fleet management (No. 13) are significantly associated with the number of tractors in the farm to support the efficient management of farmers. A graphical representation of relationships between variables is reported in Figure 3 by MCA.

The variables with objective content are directly applied for computing the factorial plane, while variables with subjective content are added as supplementary information. A significant contribution to the interpretation of the MCA output is given by respondents' ownership of technological innovations (participants reported the technological innovations available on the market that they had, or not, already adopted: variables labelled OWN_[X] and NO_[X]; where X = technological innovation, such as GPS, ABS, etc.) and by the technological innovations they wished their tractors were equipped with (variables labelled Next_[X]). Figure 3 shows, on the right side of factorial plane, the adoption of technological innovation on agricultural tractors (dark gray boxes). In fact, a dichotomy is visible between farmers positioned on the left area of the quadrant (*i.e.* those who do not work with tractors equipped with technological innovations) and those on the right area (*i.e.* those who have these technological innovations on tractors). Farm size (circled) and fleet dimensions (underlined) present a similar pattern. The smaller farms, both in terms of size and fleet, are positioned on the left side of the graph (the less technological area), while on the

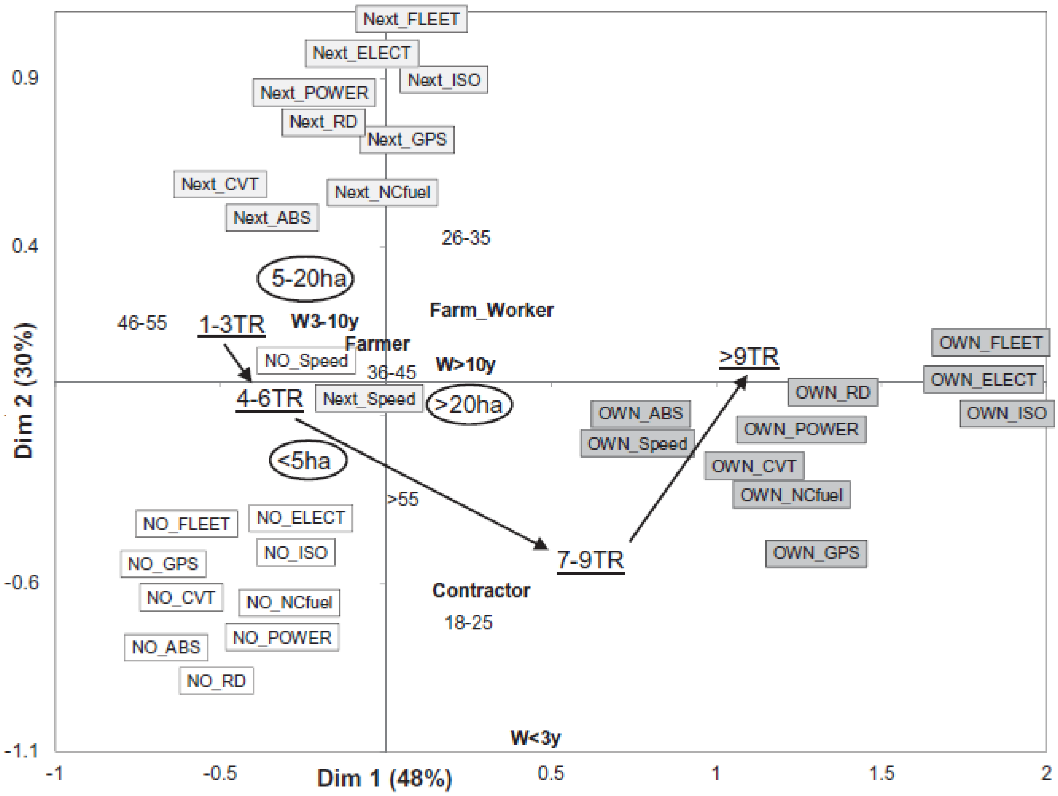


Figure 3. Multiple Correspondance Analyses (MCA). Projection of variables with objective content (1–5 and 9 in Table 1) and questions on technological innovations desired (10 in Table 1).
Note: CVT: continuously variable transmission; GPS: global positioning system; NCfuel: alternative fuels; POWER: overpower/power-boost; RD: remote diagnostics system; ISO: ISOBUS/CAN-BUS; Speed: Speed greater than 40 km/h; ABS: assisted braking systems; FLEET: fleet management; ELECT: electric actuators.
Source: Ferrari et al., 2013.

right-hand side of the factorial plane (the more technological area) we find larger farms (both in terms of size and of fleet). Hence, the first dimension (horizontal) shows the presence (right-hand side) and the lack (left-hand side) of technological innovations on agricultural tractors. In short, the statistical evidence seems to support the HP1 that technological innovations in agricultural tractors are positively associated to larger firms.

*Test of HP2*

A significant association emerged between age and importance given to the reduction in environmental impact in the use of agricultural tractors. The literature suggests that younger people are more environmentally concerned than older people (Olli, Grendstad and Wollebark 2001). On the contrary, the analysis shows a weak but statistically significative positive correlation between age and importance of low environmental impact (No. 2; *see* $r_s$). People aged 46-55 assigned the highest score to the importance to reduce the environmental impact of tractors. (*cf.* Figure 4). Nevertheless, a significant association is found between the importance assigned to the environmental impact in agricultural tractor usage and respondents' years of activity (No. 3; *see* $\chi 2$). Respondents working in this sector for more than 10 years seem to consider very important a low

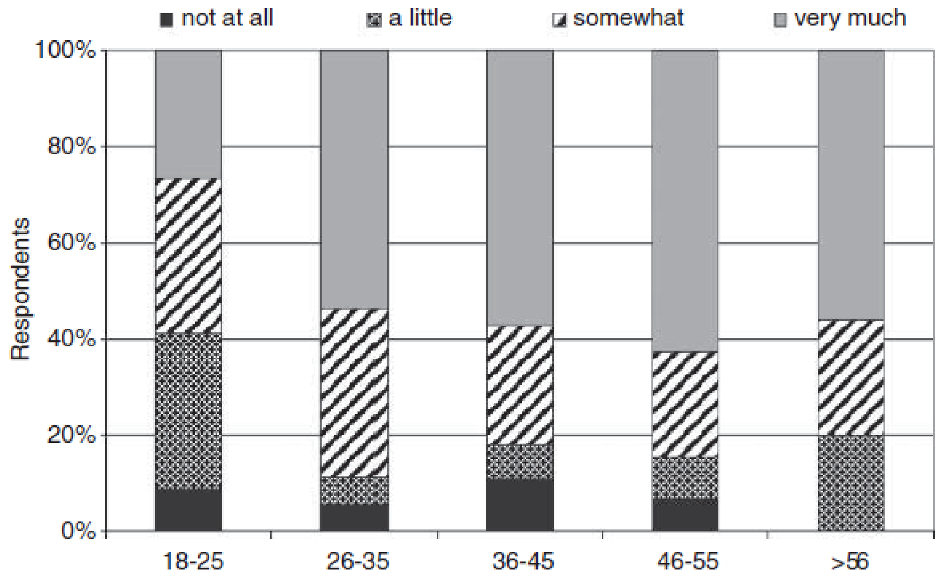


Figure 4. Importance of environmental impact reduction according to respondents' age.
Source: Ferrari et al., 2013.

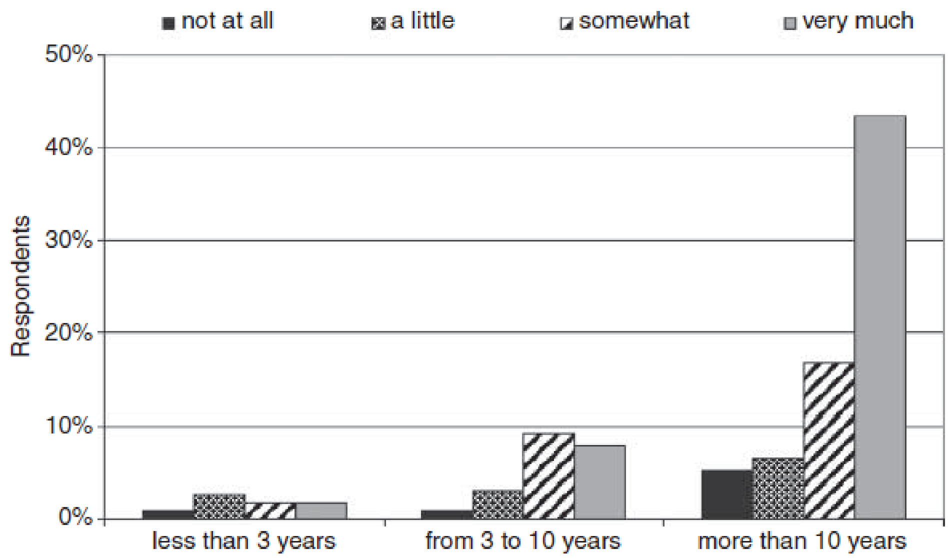


Figure 5. Importance of environmental impact reduction according to respondents' years of work.
Source: Ferrari et al., 2013.

environmental impact in tractor usage (No. 3; *see* $r_s$) (*cf.* Figure 5). At the same time, the more years they had spent working in this field, the more they believed that technological innovations of agricultural machines enable environmental impact reduction (No. 6). The hypothesis of adopters' environmental learning effect concerning the technological innovations of tractors is supported by other critical relationships. In particular, farmers working in the agricultural sector for more than 3 years believed that technological innovation increases agricultural machine safety greatly compared with farmers who had recently (less than 3 years) started *Strategic management implications for the adoption of technological innovations* 775 working in this field (No. 4). Similarly, years of activity is significantly related to the technological innovation that amplifies machine reliability (No. 5; *see* $\chi_2$), showing that the more years farmers are working in the agricultural field, the more they consider that technological innovation increases machine reliability (No. 5; *see* $r_S$). In brief, the statistical evidence tends to support the HP2 that technological innovations in agricultural tractors that reduce environmental impact are positively associated to higher expertise by farmers.

# 5. Lessons learned and concluding remarks

In advanced countries, since the 1990s, the trend of the technological innovation is driven by the development and adoption of sophisticated technology by the introduction of electronics and information and communications technologies (ICTs) within all areas of agricultural machinery (*cf.* Vieweg 2012). Knowing the preferences, expectations and needs of tractor operators could improve the allocation of human resources, budgets of innovative projects and founding of agricultural subsidies. The empirical evidence supports that technological innovation in tractors is relevant for larger farms (*HP1*). Large farms are managed more professionally and require more efficient and sophisticated machinery. On the one hand, groundbreaking technological products of tractor engineering are targeted to professional farmers, where manufacturers can capitalise on these trends (Richenhagen 2009). On the other hand, technological innovation in tractors is not the main characteristic taken into consideration by agricultural users (eg. workers). The evidence shows that technological innovation is very important to improve comfort and safety. In particular, comfort is important especially for larger farms, where the workers spend several hours on agricultural tractors. In short, the evidence highlights that high technological innovation tends to be associated to larger farms. In contrast with the literature (Olli, Grendstad and Wollebark 2001), the evidence here shows that the older the tractor users are and the longer they are working in agriculture, the higher is their commitment to environment protection and safe working conditions (*HP2*). This result seems to suggest the need to improve the environmental and safety education among young and new tractors' users. Nevertheless, the study reveals a general interest on environment protection, especially when alternative fuels are considered. It is less available and highly desirable among the innovative technologies investigated. These conclusions are of course tentative. There is need for much more detailed research into the relations between adoption of technological innovations in agricultural tractors, scale factors of firms and environmental attitude of adopters.

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## Notes

1. It is a "'model" and 'pattern' of solution of selected technological problems, based on selected principles derived from the natural science and on selected material technologies' (Dosi 1982, 152, original emphasis).
2. In general in economics, the process of agricultural development (both technical change and institutional change) is treated as exogenous. In this study, we apply the concept of induced innovation by Hicks (1932, 124–125) that argues: 'changes or differences in the relative prices of factors of production could influence the direction of invention or innovation'. Within the framework of the theory of the firm, this is an apt hypothesis to show as the (agricultural) firms can spur labour-saving innovations as well as innovations to improve energy efficiency of goods.
3. Strategic change involves an attempt to change current modes of cognition and action to enable the organisation to take advantage of important opportunities or to cope with consequential environmental threats (Gioia and Chittipeddi 1991).
4. Hectare (ha). A unit of area equal to 10,000 square meters. Equivalent to 2.471 acres.

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