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Full Research Article

Innovation adoption and farm profitability: what role for research and information sources?

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Abstract. The paper analyses the determinants of farmers' adoption of innovations and studies the effect of the source of information and the connection with agricultural research on the contribution of innovation to farm performance. The paper uses primary data collected ad hoc in the Province of Bologna (Emilia-Romagna, Italy) and analyses it through an econometric analysis. The results indicate that structural factors and farm specialisation still play a relevant role in innovation adoption. Connection to scientific research triggers significant improvements in terms of value-added and quality of production but does not affect other profitability-related parameters. The results confirm the need for policy to better consider the role of intermediate actors between research and the farmer as well as to better clarify the final performance strategy in order to set the policy instruments right. The paper also highlights the need for further research about farms' proactivity in searching for and selecting information during the process of innovation adoption and competitive advantages in terms of profitability components.

Keywords. Innovation adoption, information sources, research-innovation link, farm profitability.

JEL Codes. D83, O14, O31, O33.

1. Introduction

The interest in studying the process of innovation adoption and impact, both from theoretical and empirical perspectives, is motivated by the key role of innovation in fostering agricultural competitiveness and socio-economic growth (Ramos-Sandoval *et al.*, 2018; Sauer *et al.*, 2019). In fact, a noteworthy share of the literature to date has focused primarily on understanding the patterns of innovation diffusion, rather than adoption. In recent decades, several studies have started to broaden the research perspectives on agricultural innovation by introducing frameworks and models aimed at understanding the process of innovation adoption in agriculture (Gadhim and Pannell, 1999; Diederen *et al.*, 2002). The early approaches can be roughly classified into those mostly focusing on eco-

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nomic interpretations and those taking a more sociological perspective (Marra *et al.*, 2003). Economists have argued that adoption and diffusion of innovation is motivated by changes in economic factors, such as prices, production efficiency, risk attitude and utility, whilst sociologists have, for their part, highlighted the major role of the adopter's characteristics and the social environment in which the adoption process occurs. Although from different perspectives, both approaches have converged in identifying in the learning behaviour of individuals one of the most important factors in the innovation adoption process which, in turn, characterises the diffusion pattern (rate of adoption) (Ruttan, 1996).

Micro-level studies concerning the adoption and diffusion of innovations has progressed over time by testing new models explaining adoption and new patterns of diffusion, characterised by the inclusion of (farm level) information (uncertainty and risk) and time (diffusion as a sequence of adoptions) factors. While new insights have been identified with respect to the theoretical evolution, the empirical results provide an increasingly varied range of explanations for adoption (Ghadim and Pannell, 1999), including the recent attention to the innovation behaviour of farmers (Läpple *et al.*, 2015; Sauer *et al.*, 2019).

At the aggregate level, the evolution of theories and practices concerning the concept of innovation have moved from a linear model of knowledge transfer from public research to the farm (Röling, 1990), to the so-called agricultural knowledge system (AKS), to an even more complex and dynamic innovation process, in which different actors (including public and private stakeholders beyond the research, education and consulting/extension sectors) cooperate in a network, referred to as agricultural knowledge and (information) innovation system (AKIS) (Esposti, 2012; SCAR, 2012; Ramos-Sandoval et al, 2019). The AKIS concept supports the idea that the development and realisation of innovations are not limited to pre-defined and unidirectional processes (path-dependence, demand-pull or technology-push), as in the case of AKS, but rather fed by a multitude of processes characterised by a continuous interaction between stakeholders within a network. Such a paradigm although, on the one hand, makes the study of approaches to innovation adoption more complex, on the other hand it broadens the research perspectives by allowing for the inclusion of latent or hidden elements in modelling innovation adoption in agriculture, such as multiple information channels, for which the contribution of literature is still limited, and the role of research, recently highlighted by several European policy initiatives such as the European Innovation Partnership (EIP) and the (related) Innovation Operation Groups (IOG). An especially relevant gap in the literature concerns the link between upstream connections with research as a source of information and innovation performance on the farm, in a context characterised by the growing role of the farmer in combining information and new technologies in designing farm-level innovations.

This paper seeks to contribute to this literature through a farm-level study on the impacts of scientific research in agriculture (SRA) on the economic performance of farms taking into account the intermediary steps of innovation adoption. The paper relies mainly on primary farm-level data, collected through direct interviews with farmers using an *ad hoc* survey questionnaire, with the broad aim of collecting data suitable for analysing the determinants of farmers' adoption of innovations, the effect of innovation on farm economic outcomes, in terms of different components of profitability of the introduced innovation, and link these back to the role of research in innovation development.

The contribution of the paper is mainly on empirical grounds, using insights and variables from a wide range of literature. However, our study is inspired by concepts mainly derived from two seminal theoretical frameworks, namely *induced technical change* by Hayami and Ruttan (1985) and the *evolutionary model* by Nelson and Winter (1982). We apply a demand-driven approach, as proposed by Walker *et al.* (2010), which, together with the *recall* technique strategy, allows us to set an impact pathway, tracing back the determinants of the effects of successful innovation adoption on economic performance. In this paper, the use of the term *innovation* is intended as *new to the farm/farmer* and not as *new to the market* (Mairesse and Mohnen, 2010).

The main novelty of the paper is the attempt to clarify whether a higher farm performance might be linked to the fact that the adopted innovation is rooted in scientific research. In particular, we investigate the extent to which, and how, the fact that an innovation is known to derive from scientific research affects, beyond the adoption decision, the economic performance of the farm. The origin of innovation from scientific research is identified through collected data about prior-knowledge of farmers. Performance is also measured based on farmers' statements regarding the gains realised from the adoption of the innovation, in terms of reduced costs, increased production, higher value-added and higher product quality.

We investigate the effects of information on the adoption decision processes in two steps. After having presented the survey results in terms of descriptive statistics, we first analyse which factors and processes influence farmers' decisions to adopt, or not to adopt, new technologies; then, as concerns the innovators (the farmers who introduced an innovation), we investigate whether the origin of innovation from scientific research yielded effects on profitability at farm level.

The paper continues with a literature review in section 2. The methodology is outlined in section 3, followed by the presentation of the case study area (Province of Bologna, Emilia-Romagna) in section 4. Section 5 illustrates the results, followed by a discussion in section 6 and concluding remarks in section 7.

2. Literature review

Early studies on innovation adoption at farm level focused mostly on disentangling the innovation adoption process through a micro-economic approach (Cochrane, 1958; Hayami and Ruttan, 1985; Thirtle, 1985), by relying on the basic assumption of profit maximisation as the main economic driver for adoption (Sunding and Zilberman, 2001). On the other side, recent studies on innovation in agriculture, although relying on the same framework, focus more on the variety of different elements determining the adoption, as well as the diffusion processes. Indeed, Hall (2012) sketches how the modern innovation adoption process goes largely beyond the (public) function of introducing technology to farmers, as exogenously intended by Cochrane (1958) and Hayami and Ruttan (1985), conceiving the innovation in agriculture as a system in which partnership, alliance and network actors work together to develop and spread innovation. A fundamental role in this system is acknowledged to be played by *producers* and *users* of knowledge, but the issue of who and how such links are created is still very much under scrutiny. Indeed, the multiplicity of underlying dynamics characterising the links between the actors of the agricultural innovation system might be at the basis of the discordant findings of studies on innovation adoption. In fact, recent studies on the topic have addressed this issue and are evolving towards the definition and role of knowledge and/or innovation brokers within the AKIS (Klerkx *et al.*, 2009; Ramos-Sandoval et al, 2019).

As regards the adoption of innovation in agriculture, in fact, different studies report varied results with regard to the relative importance of different determinants of adoption (Ghadim and Pannell, 1999), such as education, credit constraints, land size and others (Feder and Umali, 1993). One reason for such discordant results can be attributed to the difficulty in relating empirical information, model hypotheses and the conceptual/theoretical framework in which innovation adoption in agriculture is modelled (Lindner, 1987; Besley and Case, 1993). In fact, the evolution of the theoretical framework progressed towards the inclusion of informational attributes (Koundouri *et al.*, 2006; Walder *et al.*, 2019) and learning behaviour (Ramos-Sandoval *et al.*, 2018) into the models hence making it possible to envisage innovation adoption as a dynamic process. Information has played a major role in modelling the uncertainty concerning adoption decisions as well as farmers' risk attitudes and risk aversion behaviour in the face of uncertainty. Indeed, in a context of incomplete information, the degree of risk perception is assumed to be affected by learning, as learning can reduce the uncertainty concerning the innovation adoption (especially the downside production risk) (Marra *et al.*, 2003; Koundouri *et al.*, 2006). Time, especially in connection to learning, is another important factor characterising the speed and rate of aggregate adoption and, hence, diffusion (Sunding and Zilberman, 2001). Other additional factors beyond profitability, such as environmental and social sustainability concerns, potentially determining innovation adoption have been explored as well (Walder *et al.*, 2019).

In relation to the above, diffusion itself has been subject to different interpretations. In economic terms it can still be interpreted as depending mostly on the perceived short-run profitability of the innovation (Levins and Cochrane, 1996; Diederen *et al.*, 2002). However, from a more sociological perspective, innovation diffusion also depends on the spread of information and is negatively related to the distance from the propagation point (Rogers, 1983). Improvements in human capital through learning affect positively the adoption rate and diffusion of innovation. Based on this concept and starting from the evolutionary model of Nelson and Winter (1982), a stream of research advanced up to the adaptation of the technology acceptance model (TAM), proposed by Davis (1989), to the farming sector (Flett *et al.*, 2004; Folorunso *et al.*, 2008; Rezaei-Moghaddam and Salehi, 2010). Through TAM, innovation adoption is explained as a process that depends on the perceived usefulness and perceived ease of use of the technology which, in turn, affects the acceptance (and the adoption) of the innovation. This theoretical framework belongs mainly to the psychological perspectives of the topic and attributes more importance to the individual beliefs and perceptions underlying the learning behaviour involved in the adoption process.

A noteworthy gap in the literature concerns investigating whether and how the origin of innovation, and in particular research, may be related to the economic performance of innovation adopted by the farms[1]. Two aspects can be distinguished: a) one is the "objec-

[1] This topic has been recently explored by Hockmann et al. (2018) in the food processing sector, evaluating the impact of internal R&D activities on the economic performance of multinational corporations.

tive" origin of innovation; and b) the second is the knowledge of the origin. This distinction and the attribution of innovation to specific events or projects is often difficult due to the fact that multiple players and activities may contribute to its development, including the farmers themselves.

As demonstrated in the literature, knowledge about innovation, improved through learning, plays a central role in the adoption process (Marra *et al.*, 2003). This holds especially in agriculture where the relatively high costs of internal R&D activities do not allow for the easy and affordable development of innovations within the farm (Sunding and Zilberman, 2001; Diederen *et al.*, 2003). For a large part of the literature, the positive role of knowledge by the farmer in the process of innovation adoption is referred to (or limited to) the adoption of available innovations and limited to the features of innovative technologies/solutions, disregarding its origin. In particular, learning (ability) is mostly considered to be a skill that makes the farmer (the innovator) able to reduce the downside risk of the innovation adoption and to improve the performance of the innovation through a process of adaptation to his/her farm's peculiar characteristics.

This approach implicitly assumes that the learning behaviour is considered to be detached from the path leading from research to innovation. Instead, here we assume that knowledge about the innovation development process matters in terms of improved adoption processes and economic performance of the farm. This view is consistent with theoretical frameworks and empirical evidence that highlight how the cognitive elements of the innovator, such as his/her educational background (Lin, 1991; Reimers and Klasen, 2013), attainments and experience (Foster and Rosenzweig, 1995), affect positively both adoption and performance of innovations (Sauer *et al.*, 2019), though (knowledge about) origin is not generally explicitly addressed. Moreover, this hypothesis easily accommodates the theoretical framework pertaining to AKIS, according to which farmers interact with articulated networks of actors in the innovation research, development and adoption processes and may hence be aware of, or participate in, the research stages of innovation development or in the further stages of knowledge dissemination (SCAR, 2012). In this paper, we consider both the knowledge of research generating the innovation and the sources of information about the innovation as potential factors affecting the economic performance of innovation adoption.

3. Methodology

3.1 Overall approach

The analysis proposed in this paper seeks to link information, research and farm-level performance by analysing the declared effects of innovation introduction with respect to farm structural factors, farmers' characteristics and elements related to the process of innovation adoption, such as the sources of information, specifically the origin from research. The main objective of our study (besides explaining innovation adoption) is to evaluate whether the effects of adopted innovation on farm profitability is affected by the origin of the adopted innovation, in particular how innovation originating from research can affect various aspects of farm performance in different ways.

The paper is based on survey data, provided from farmers' responses to questions. This will require some qualifications, which are provided in the discussion section.

As mentioned, the paper does not refer to one specific theoretical framework. However, the set of explanatory variables draws mainly from the analysed literature, which is grounded upon the *induced technical change* theory by Hayami and Ruttan (1985), for which innovation adoption is responsive to both economic conjuncture and technical evolution brought about by R&D, and the *evolutionary model* (Nelson and Winter, 1982), according to which farmers put effort into searching for better techniques and the selection of successful innovations (local searches for innovations, imitation of the practices of others and satisficing economic behaviour). These theoretical frameworks are integrated with insights drawn from the most recent literature on the AKIS framework and innovation adoption, especially considering linkages with non-farm actors, different sources of information and personal attitudes towards adoption. The theoretical development of the topic involves further aspects of the process in order to better qualify innovation adoption and diffusion, such as diffusion in terms of imitation of adoption, timing of adoption, endogenous and exogenous factors affecting adoption, elements characterising heterogeneity of farmers, etc.

In order to address the evolving theoretical framework and to adapt to available data, a variety of methodological approaches have been used in the literature. Sunding and Zilbermann (2001), in reviewing the innovation process in agriculture, argued that the analytical methodologies mostly suited to evaluate the process of technology/innovation adoption are the binary or the limited dependent variable approaches. This opinion hinges upon the fact that innovation adoption is regarded as a discrete choice and, as such, represented by the means of threshold models. Alternative and more articulated approaches have been employed over time, e.g. Ghadim and Pannell (1999) adopted time-series methodologies, Diederen *et al.* (2002, 2003) used nested and ordered logit models, Dimara and Skuras (2003) tested the application of partial observability models, while Koundouri et al (2006) applied a two-stage binary choice model.

Given that the objectives of the present study mainly pertain to the evaluation of the effects of different elements of the innovation adoption process on both the adoption choice itself and the consequences of the adoption in terms of positive economic performance, we use econometric techniques belonging to the class of limited dependent variable models on cross-section data derived from an original survey.

3.2 Methodological approach

A two-stage conceptual framework is employed for modelling the analysis. The first stage concerns farmers' choice to adopt an innovation and the second concerns the profitability of the adopted innovation. The underlying process is composed by a participation stage and an outcome stage, where the outcome depends on the participation: the first stage is about the choice to adopt or not and, conditional on this first decision, the second is about the economic performance of the adopted innovation.

An expected utility maximization framework is used to examine farmers' choice to adopt, including the sequential adoptions as well. Assuming that farmers are profit oriented and that their expected utility depends on the level of profit earned, the objective function of the farmers will be to maximize expected utility through maximizing expected profits (posed that utility is monotonically increasing in expected profit). It follows that a higher profit implies a higher expected utility for farmers.

Thus, for the i_{th} farmer: $U_i=U(\pi_i(I_i,X_i,S_i))$, where U_i is expected utility of farmer i, π_i is expected profit of farmer i, I_i is the innovation adopted (that guaranteed the highest performance) by farmer i, X_i is vector of determinants of adoption of farmer i that impact expected profits of production, and S_i is a vector of other factors affecting the ability of farmer i of generating profit.

According to Lynes *et al.* (2016), the choice of adopting an innovation occurs if the expected utility U_i, expressed in terms of expected profit from the adoption of I_i, is greater than the expected utility of no adoption, namely *no* I_i. Assuming that the choice of I_i depends on X_i and S_i as well, $I_i(X_i,S_i)$ and by simplifying the notation, so that U_i is stated as a function of I_i, the following condition applies: $U_i(I_i)>U_i(no\ I_i)$, such that $U_i(I_i)-U_i(no\ I_i)= \Delta(U_i)>0$.

Expected higher profits, i.e. the *outcome*, is dependent on the choice of adopting, i.e. the *participation*. The outcome stage can be identified according to two different specifications. On one hand, the outcome of adopting an innovation, as suggested by Cochrane (1958) and Levins *et al.* (1996), can be intended as a continuous choice or a sequence of adoptions, namely more than one adoption, in order to guarantee, according to the *technology treadmill*, the competitiveness and the profitability of the farm. On the other hand, the outcome stage can be meant as the profitability consequent to the adoption of a specific innovation, namely the realized economic performance resulting from the introduction of the innovation into the farm.

In both cases, it is assumed that farmers who choose to adopt knows that the outcome is affected by adoption determinants, such as structural factor (farm size, specialization, mechanization, market), subjective characteristics of the farmer (education, experience, off-farm income, business motivation, entrepreneurial attitude), but they also know that, to maximize the profitability, innovations need to be introduced after a learning process has been made and after that other elements have been scrutinized and evaluated accurately, such as the ability of self-developing the innovation, trial and error, the sources of information from others and links with R&D. Expected higher profit can, therefore, be considered as an indirect function of both the determinants, the farmers' subjective characteristics and the learning process leading to the adoption of a specific innovation. The stage two can be represented as follows: $\pi_i[I_i(X_i,S_i)]>0$, for which $\frac{\partial I_i}{\partial S_i}>0$, $\frac{\partial \pi_i}{\partial I_i}>0$ and, in turn, $\frac{\partial \pi_i}{\partial S_i}>0$, while $\frac{\partial I_i}{\partial X_i}$ is ambiguous.

3.3 Econometric modelling strategy

The econometric modelling strategy proceeds in two main steps: first, we provide an analysis of the adoption choice; then we proceed by explaining the performance and connecting it to the source of information. In order to avoid potential confusion across analyses and models, the first group is called *adoption models*, while the second is referred to as *performance models*.

The analytical models chosen to analyse such variables belong to the class of limited dependent variable models. In the general case, the choice to adopt, namely the *adoption model*, is observed as a binary action, representing the underlying outcome of the utility maximization: if $Y_{ai}=1$ means that $\Delta(U_i)>0$, while in the opposite case $Y_{ai}=0$. That is, $Y_{ai}=1$ when farmer i chooses to adopt the innovation, and $Y_{ai}=0$ otherwise. Determinants of (X_i)

and other factors (S_i) are assumed to linearly affect the adoption decision related to the farmers' choice to adopt. Let $Z_{ai}(Z_{a1},\ldots,Z_{ak})$ be the set of both the determinants of (X_i) and the other factors (S_i) affecting the adoption choice, $a_{ai}(a_{a1},\ldots,a_{ak})$ be a vector of parameters and ε_i be a mean zero IID error term.

Then, the adoption choice can be modelled as: $\Delta(U_i) = \alpha_{ai}Z_{ai} + \varepsilon_i, Y_{ai} = \begin{cases} 1\ if\ \Delta(U_i) > 0 \\ 0\ otherwise \end{cases}$.

The choice variable is simply the record of the adoptions, recorded as a single choice (in the case of one innovation) and as a sequence of choices (in the case of more than one innovation). This part of the analysis was carried out by evaluating the determinants of both the propensity to innovate and the number of innovations introduced, by employing a *Probit* and a *Poisson* model, respectively. In addition, a *Double-hurdle* model has been used. This type of model has the advantage of making it possible to analyse the number of adoptions (single or repeated) that are conditional on the analysis of the choice to innovate (participation), which potentially follows a different data generating process (or, rather, that may be affected by different explanatory variables). The additional contribution of the *double-hurdle* regression is the capacity to clearly separate the factors mainly affecting the choice from those mostly affecting the adoption. The determinants include the technical and commercial characteristics of the farms and the subjective, socio-demographic characteristics of the farmers. Other factors include the motivations of farmers to innovate, the knowledge of the adopted innovation prior to its adoption, the sources of information that farmers consulted, including the origin of innovation from scientific research, as well as whether farmers developed the innovation by themselves.

Following the same rationale, the profitability induced by the adopted innovation, namely the *performance model*, is observed as a binary outcome as well: if Y_{bi}=1 means that $\frac{\partial \pi_i}{\partial I_i}$>0, while in the opposite case Y_{bi}=0. That is, Y_{bi}=1 when the adopted innovation yielded an improvement in profitability and Y_{bi}=0 otherwise. Even in this case, determinants of (X_i) and other factors (S_i) are assumed to linearly affect the improvement in profitability. Let $Z_{bi}(Z_{b1},\ldots,Z_{bk})$ be the set of both the determinants of (X_i) and the other factors (S_i) affecting the profitability (they do not need to be the same employed in step one), $\alpha_{bi}(\alpha_{b1},\ldots,\alpha_{bk})$ be a vector of parameters and ξ_i be a mean zero IID error term.

Then, the profitability can be modelled as: $\pi_i(I_i) = \alpha_{bi}Z_{bi} + \xi_i, Y_{bi} = \begin{cases} 1\ if\ \pi_i(I_i) > 0 \\ 0\ otherwise \end{cases}$.

The determinants are the same as the previous analytical model, while other factors include the motivations of farmers to innovate, the knowledge of the adopted innovation prior to its adoption, the sources of information that farmers consulted, including the origin of innovation from scientific research, as well as whether farmers developed the innovation by themselves.

Profitability is the measure of the realized gains, based on farmers' declarations, resulting from the introduction of the innovation, in terms of *cost reduction*, *production increase, value-added increase* and *quality increase*. The first three have been collected in per cent terms, while the last in ordinal categorical terms (*not at all*, *low*, *high*, *very high*). However, they have been transformed in binary variables in order to evaluate solely the presence (not the magnitude) of the declared (positive) effects of the introduced innovation. However, given the use of the *recall* technique, these variables could suffer from approximation due to difficulties in providing precise estimates of the actual amount (Mairesse and Mohnen, 2010). Such potential measurement errors could lead to biases in estimates and inefficient statistical conclusions and, in turn, render the use of the Tobit model ineffective. Despite this, these data provide for (i) important quantitative information, when used for explorative descriptive statistics and for comparative exercises, and (ii) qualitative information, when opportunely transformed into binary or categorical variables, to be used in econometric models for inferential purposes. Indeed, the hypothesis of experiencing *better performance* if the innovator knows that the adopted innovation is derived from research could be reformulated in terms of *positive (or non-null) performances*. This implies the cost of losing the magnitude of the effect (marginal effect) but, at the same time, the benefit of at least keeping the presence of the effect (propensity of experiencing a positive outcome).

Such a perspective makes it possible to approach the analysis by considering the measured performance in terms of latent continuous variables and, in turn, by employing a *Probit* and a *Heckit* model, with the aim, respectively, of analysing the propensity of obtaining positive performances, with regard to the innovators, and of accounting for the possible presence of sample selection bias. In fact, the presence of positive performance outcomes due to the research-innovation link might depend upon the self-selection process of those farmers who decided to innovate because of higher expected gains. Each model has been applied separately to each of the four performance variables, using the same set of explanatory variables.

The analysis on economic performance has the same specification of the *probit adoption* regression with the inclusion of the *other factors*, namely the variables accounting for knowledge of the research-innovation link and source of information (hereafter "information variables"). Specifically, the *research-innovation link* is the variable expressing whether the farmer is informed that the innovation originated from research, while *source of information* indicates whether the farmer knew about the innovation from external sources or developed the innovation by himself. *Age of innovation,* for its part, is a measure of time distance between the year of introduction and 2015 (maximum 20 years) and is a proxy of farmers' experience using such innovation (fine-tuning of innovation usage) as well as for the innovation to fully express its effects in terms of economic performance. The dependent variables used in the *probit performance* models are *cost reduction*, *production increase*, *value-added increase* and *quality increment*, all expressed as binary variables.

3.4 Survey: sampling procedure and questionnaire

A survey strategy was adopted because of the absence of datasets on innovation adoption processes and/or the existence of datasets characterised by noteworthy margins of non-representativeness and of collection/transcription errors, such as the ones operated by regional administrations to evaluate measures of the Rural Development Plans (RDP) or the regional level FADN data. The survey strategy represents an appropriate research tool for this work because, like similar research works, this type of approach is preferred for anticipatory/forecast purposes and for studying elements and factors that are much more difficult to identify, such as the innovation adoption process (Besley and Case, 1993).

The sampling plan, aimed at collecting complete information from at least 300 farms in the Province of Bologna, randomly picked from a sequential selection of about 1000 farms, constrained to be representative of both the agricultural specialization (type of farming) and the altitude level.

The data have been collected by the way of an *ad hoc* questionnaire, first checked through direct interviews, further adapted to be used by telephone and finally carried out by telephone interviews (of approximately 15 minutes in length).

The survey was designed to collect information about the farm, information about the farmer, specific elements pertaining to the innovation adoption process realised by the farmer and, in sequence, the relative effects on farms' economic performance from the adopted innovation.

The questionnaire is structured in six sections:

- The introduction presents the aims of the survey and the project it relates to (EU FP7 project IMPRESA);
- The first section includes questions about farm structure: production specialisation and ancillary activities; land, labour, machines, technological plants;
- The second section deals with the adoption process, including the choice of innovating, the number and types of innovations introduced, the motivation for, and for not, innovating;
- The third section concerns one introduced innovation, namely the most important innovation (in terms of profitability), the sources of information and the link with research;
- The fourth section addresses the financial aspects of innovation adoption, in particular whether the innovators benefited from supports from the Common Agricultural Policy (CAP) and the amount of total investments;
- The fifth section deals with the effects of the adopted innovation in terms of economic performance: perceived changes in costs (efficiency gains), in production (output gains), in value-added products and (higher) product quality;
- The sixth section includes questions about future behaviour of the farmers and expectations/sentiments with respect to the CAP;
- The last seventh and final section includes questions about the socio-demographic characteristics of the farm and the farmer's family.

The first and the last sections of the questionnaire aim to collect, respectively, structural (objective) data about the farms and socio-demographic (subjective) data about the farmers, focusing on those elements considered in the literature as "classic" determinants of innovation adoption, such as specialisation, size, mechanization, altitude, farm income, education, and experience. The second section inquiries into the process of innovation adoption by first exploring (eliciting) the opinion of the farmer about the existence of important innovations (in terms of profitability) in his specialisation sector in the last 20 years. The subsequent information regards the types of innovation introduced on the farm in the last 20 years, as well as the choice of not introducing any particular innovation, specifying innovation with regard to products, production factors and process innovations. Crossing these two types of information makes it possible to clearly frame the individual choice context in which the adoption process has been developed. In this section, the farmer indicates which of the introduced innovations is, in his/her view, the most important in terms of profitability. The third section focuses solely on the most important innovation indicated by the farmer and deals mainly with the motivations underlying the adoption. This section has been built on the basis of the *Induced Innovation Adoption* (IIA) by Hayami and Ruttan (1985) and the *evolutionary model* (EM) by Nelson and Winter (1982). With regard to the IIA, farmers were asked whether the choice of innovating was determined, *inter alia*, also by a reaction to changes in products' and factors' prices or by the intention to anticipate the evolution of the markets of both products and production factors. Further, the condition of being early adopters or laggards has been investigated by asking farmers for how long the introduced innovation was already commonly used. As regards the EM, farmers were questioned about the origin of the introduced innovations, with the aim of exploring the connections between the farmer and the other actors involved in the AKIS, including the research sector. In primis, a distinction was made between farmers who stated to have created/developed the innovation by themselves (*self-innovators*) and those who declared to have learned of the innovation from *external sources*. In this way, for the latter, the information channels can be explored in more detail by referring to a menu of possible sources. The external sources are split into three groups: institutional, market and acquaintances. The institutional group includes sources related to the sphere of agricultural research and extension, such as universities, research centres and other private and public entities (i.e. regional administrations, local authorities, R&D from firms, training etc.); the market group refers to the sources of information from producers, retailers and commercial agents; whereas the acquaintances group involves as a source of information the network of people surrounding each farmer, such as relatives, neighbours and others. This section seeks to highlight the role of information and research, namely the elements representing the potential contribution to further understanding the innovation adoption process as well as the relative weight of agricultural research to the farm-level effects of innovation adoption. The key element meant to establish a connection between external sources and effectiveness of the adopted innovation is the investigation of the *research-innovation link* that is whether the farmers know about the research behind the development of the adopted innovation.

The fifth section is dedicated to the declared effects of the introduced innovation in terms of changes in economic performance, combination of inputs and leisure time. Information on the effects on economic performance of the introduced innovation were collected by breaking down the profitability into four elements: *Cost Reduction, Production Increase, Value-Added Increase and Quality Increase.* The importance of these variables within the context of the innovation adoption process is found in their potential to reveal the mechanism allowing the adopted innovation to contribute to the farms' overall economic performance (profit). The sixth section investigates the future intentions of the farmers regarding the continuation of the agricultural activity and the adoption of further innovations in the next five years. Further inquiries are posed in order to record the opinions of farmers about the relationship between innovation and agricultural policy, as well as the role of innovation for the improvement of competitiveness in agriculture. The last section concludes the questionnaire by inquiring into the future of the farm and of the farmers and eliciting opinions about innovation and the CAP. The data collected in this section are used for supporting the evaluation of, and better interpreting, some farmers' choices, such as the motivations for not innovating.

Most of the data collected have been recorded as binary or categorical variables, whilst data related to farm size, labour, introduced innovations and others, have been recorded as continuous variables. Exceptions are represented by the information related to farms' economic performance, which has been surveyed according to four variables, namely *cost reduction*, *production increase* and *value-added increase*, collected in per cent terms, and *quality increase*, recorded according to an ordinal categorical variable (*not at all*, *low*, *high*, *very high*).

4. Case study area, data collection process and descriptive statistics

4.1 Case study area

The agricultural sector in Emilia-Romagna is one of the most advanced and productive in Italy, due to the favourable geographical and climatic conditions (the southern part of the territory is mountainous, whilst the northern part belongs to the Po valley, which is a very fertile zone), and the presence of highly specialised enterprises. Emilia-Romagna is particularly active in the production of cereals (wheat and maize), fruit and livestock (mainly bovines, pigs and poultry) (Fanfani and Pieri, 2016).

The Province of Bologna is located in the central part of the region, is agriculturally varied and composed of plains, hilly and mountain areas. According to the last agricultural census carried out in 2010 by the Italian Institute of Statistics (ISTAT), the Province of Bologna accounts for about 10,800 agricultural units over an UAA[2] of about 173,000 ha.

As shown in Table 1, the agricultural sector is mainly based on arable crops, involving about 7,000 farms and about 141,000 ha of UAA. Arable crop farming is mainly composed of farms growing cereals (about 4,000) and forage (about 2,000), whose UAA shares are 53% and 27%, respectively. The average size of farms producing cereals and forage crops is 12 and 10 ha, respectively, and more than half of them are located in plain areas. The second major type of farming in the province is livestock and related activities, involving about 800 cattle-holding farms with 33,000 heads as well as 150 swine-breeding farms and 75,000 heads. The largest livestock farms are based in plain areas.

Regarding fruit cultivation, about 2,700 farms grow orchards over an UAA of about 16,000 ha.

Table 1. Agricultural census data per specialization (type of farming) and altitude level.

Specialization	Plain	Hill	Mountain	Total	
Cattle farms (Milk, Beef, ovine-caprine and mixed)	295	454	369	**1118**	10%
Cereal crops (wheat, maize, oats, barley)	3177	633	187	**3997**	37%
Other arable crops (open field, horticultural, mixed and grain pulses crops)	1284	849	608	**2741**	25%
Fruit (orchards, olives and grapes)	1529	1082	90	**2701**	25%
Non-classifiable	65	109	28	**202**	2%
Total	**6350**	**3127**	**1282**	**10759**	
	59%	29%	12%		

Source: our elaboration on ISTAT data.

[2] UAA stands for 'Utilised Agricultural Area'.

4.2 Sample data and selected descriptive statistics

The sample, represented in Table 2, includes 178 farms located in the plains (59%), 87 in hilly (29%) and 35 in mountain (12%) areas. According to the principal specialisation, the sample is composed of 20 livestock farms, 116 cereal farms, 69 'other arable' crop farms, 88 fruit farms (including olives, grapes and 11 nurseries), and 7 non-classifiable farms. Cereal crop results are the most frequent specialisation with about 39% of the total farms, followed by fruit farms (about 26%), arable crop farms (22%) and cattle farms (7%). Given that it is a direct result of the sampling procedure, the sample can be considered to be representative of the Province of Bologna.

Table 2. Sample units per specialisation (type of farming) and altitude level.

Specialisation	Plain	Hill	Mountain	Total	
Cattle farms (Milk, Beef, pork and mixed)	5	7	8	**20**	7%
Cereal crops (wheat, maize, oats, barley)	86	21	9	**116**	39%
Other arable crops (open field, horticultural, mixed and grain pulses crops)	33	21	15	**69**	23%
Fruit (orchards, olives and grapes)	49	36	3	**88**	29%
Non-classifiable	5	2		**7**	2%
Total	**178**	**87**	**35**	**300**	
	59%	29%	12%		

Source: our elaboration of primary data collected.

The sample accounts for about 8,000 ha of UAA, of which about 5,000 in ownership. The larger share of the land is that of cereal crop farms with about 36% of total land, followed by cattle farms (27%), (arable) crop farms (18%) and fruit farms (15%). The descriptive statistics of the collected data are presented in Table 1A (see Annex), while a wider presentation of the statistics of the sections from second to fifth is illustrated in the results section.

5. Results

5.1 Descriptive results

Altogether, 121 out of 300 farmers adopted at least one innovation in the last twenty years (about 40%) (the precise question was "*in the last 20 years, what kind of product or process innovations have been introduced on your farm?*"). This question was posed after asking the farmers about the existence of important innovations in agriculture ("*Do you believe that in the last 20 years there have been very important innovations in your main field of specialisation (measured in terms of income)?*"). Almost 47% (140 out of 300) of respondents replied positively. Table 3 provides an illustration of these results by crossing the answers to these two questions.

Table 3. Cross-tabulation of innovation introduction and consideration of important innovations in the last 20 years.

		Introduction of at least one innovation in the last 20 years		Total
		No	Yes	
Important innovations in the last 20 years	**No**	125	35	**160**
	Yes	54	86	**140**
	Total	**179**	**121**	300

Source: own elaboration on collected data.

The consistent replies on the diagonal combinations (*No-No* and *Yes-Yes*) are somehow intuitive, while a less straightforward reasoning may emerge from an analysis of the off-diagonal cross-answers. We discuss these four options, in turn, by also attaching some descriptive statistics of the farmers/farms belonging to each combination.

The 125 *No-No* answers (roughly 42% of the sample) are composed of 50% cereal, 26% other arable crop and 15% orchard growers. With respect to the total of each specialisation, cereal growers represent 54% (63 out of 116), other arable crop, 49% (33 out of 67) and the orchard growers, 25% (19 out of 77). These 125 respondents are mainly small farms with low agricultural income. In fact, on average, 83% of them operate on less than 20 hectares and 76% of them have an income from agricultural activities that accounts for less than 30% of family income. Such conditions are consistent with the declared reasons for 'no adoption', mainly related to high costs.

The 54 *Yes-No* answers indicate no adoption in spite of the existence of important innovations in the sector of specialisation. These 54 farms are composed of 41% cereal, 24% other arable crops and 30% orchard growers. With respect to the total of each specialisation, cereal growers represent 19% (22 out of 116), other arable crop, 19% (13 out of 67) and the orchard growers, 21% (16 out of 77). This group also is composed of small farms with low agricultural income, but the frequency of these types of farms is slightly lower than in the previous group. In fact, on average, 72% of them operate on less than 20 hectares and 71% receive an income from agricultural activities that is less than 30% of family income. In this case also, such conditions seem to be consistent with the declared reasons for 'no adoption', mainly related to high costs, the expectation of soon retiring from farming (cereal) and maintaining production traditions (orchard).

The 35 *No-Yes* replies indicate adoption despite the declaration that there have been no important innovations in the sector of specialisation. These 35 farms are composed of 17% livestock farms, 43% cereal producers, 9% of other arable crops and 26% of orchard growers. With respect to the total of each specialisation, livestock farms represent 30% (6 out of 22), cereal growers, 13% (15 out of 116), other arable crops, 4% (3 out of 67) and the orchard growers, 12% (9 out of 77). This group of innovators is characterised by the fact that they operate on larger farms with higher agricultural incomes. In fact, on average, only 47% of them operate on less than 20 hectares and 49% receive an income from agricultural activities that is less than 30% of family income. These figures clearly differ from those of the previous two groups and the declared motivations for having introduced at least one innovation (with positive effects on profitability) mostly refer to reducing costs and increasing production. Both groups, and in particular the first one, are consistent with innovations that are more linked to late adoption of existing solutions motivated by economies of scale, rather than by strong innovation behaviour.

In the last group, the 86 *Yes-Yes* replies consist of 12% of livestock farms, 19% of cereal producers, 21% of other arable crops and 38% of orchard growers. With respect to the total of each specialisation, livestock farms represent 45% (10 out of 22), cereal growers 14% (16 out of 116), other arable crops 28% (18 out of 67) and the orchard growers represent 43% (33 out of 77). This other group of innovators operates on farms with sizes similar to the ones of the previous group, but with higher agricultural income. In fact, on average, 43% of them operate on less than 20 hectares and only 27% of them obtain an income from agricultural activities that is less than 30% of family income. Similarly to the previous group, this last group also indicates as the main motivations for adopting at least one innovation (with positive effects on profitability) cost reduction and production increases, with the addition of other motivations pertaining to the improvement of labour conditions, such as reducing fatigue and improving the safety of workers. This profile, which is particularly consistent with the orchard specialisation, denotes farmers who are focusing on agricultural production on well-structured farms and who are open to an understanding of the outside markets' trends as well as who are highly focused on innovation.

On the other hand, about three-fifths of the interviewees (179 farmers) decided not to innovate due to the economic and managerial hurdles that reduce the capacity of farmers to obtain new technology and adopt innovations[3]. We asked these farmers to motivate their decision not to adopt innovation by choosing among two categories of responses: obstacles and intentional choice. Among the obstacles, we proposed high costs, bureaucracy and risks, while for intentional choice we asked about ethical reasons, the intention to quit the business, negative past experiences and the desire to maintain traditional production processes. Eighty-four (84) out of 179 replies deemed the excessive costs of adopting innovations to be the main hurdle, while 16 and 18 answers indicated their intention to quit the business soon and to keep maintain production traditions, among the intentional choice group, respectively. Therefore, the sample revealed that the main reason for not having adopted innovations in the last 20 years was the excessive cost, highlighting economic barriers and the lack of managerial skills for gaining access to new technology. However, since for 33 out of 51 (65%) other reasons were expressed by cereal farms, we deduce that for about two-thirds of respondents such choice is due to a disinterest in innovation given that they possess less than 20 hectares, no weeding and harvesting machines, and therefore opt for the services of other companies. This is an important point considering the recent structural trends as it points at a dichotomy between larger professional farms, for which innovation remains important, and small farms that keep land tenure but farm via contracts, for which innovation is rather carried out or adopted by contractors themselves, i.e. outside the farm. For the remaining third, we equally deduce that they have not been interested in adopting innovations, but unlike the pre-

[3] Detailed descriptions of such data have been omitted in order to save text. These are, however, available from the authors upon request.

vious farmers, because the technology they possess is considered to still be effective and hence does not need to be replaced or upgraded.

The number of innovations introduced in the last 20 years is more than 200 for 121 innovators (an average rate of about 2 innovations per farmer).

The distribution of adoptions, shown in Table 4, reveals that mechanical innovations are the most frequently adopted ones (32%), followed by energy-water saving (21%), diversification (15%) and biological, agricultural and informatics (about 8% each). The distribution of type of innovations changes if considering the unique (most important) innovation that, according to farmers, yielded the highest impact on profitability. In fact, the shares of mechanical (42%) and energy-water saving (25%) innovations increases, while the others decreased slightly. As for motivations, the adoption of these types of innovations is mainly motivated by the need to reduce costs, to increase production and to face new climatic challenges affecting the availability of natural resources, such as water.

As concerns the timing of introduction, about 65% of the mechanical innovations were introduced during the 2010-2015 period, while about 66% of the energy-water saving technologies were adopted in the 2005-2015 period. The adoption timing of the other types of innovation is smoothly spread across the considered time span (1995-2015).

The main reasons motivating the adoption of the (one) most important innovation are concentrated in cost reduction (66 or 35%) and production increase (56 or 30%) (122

Table 4. Number of innovations introduced in the last 20 years and selection of the most important in terms of profitability.

Type of adopted innovations	All adoptions	Share of adoptions on total	Unique adoption considered most-important in terms of impact on profitability	Share of important innovations on total
Biological-Genetic	18	8.5%	8	7.5%
Diversification or Manufacturing	32	15.0%	15	14.0%
Agricultural-Zootechnic	18	8.5%	7	6.5%
Mechanical-Automation	68	31.9%	45	42.1%
Informatics	17	8.0%	2	1.9%
Energy-Water saving (irrigation plants, solar panels, biogas)	44	20.7%	27	25.2%
Marketing strategies (quality systems, production protocols)	5	2.3%	2	1.9%
Operational (cooperatives, associations, logistics)	2	0.9%		0
Other	9	4.2%	1	0.9%
Total adoptions	**213**	**100%**	**107**	**100%**
Does not know			14	

Source: own elaboration on collected data.

replies out of 187)[4]. However, out of these 122 replies, 31 prove to be jointly chosen by the same farmer, indicating an important synergy between the two aspects in contributing to the increase of profitability[5]. Other motivations, collected in open format, result in general profitability improvement, without any reference to specific motivation, and reduction of worker fatigue. The main motivations for cost reduction and production increases are more frequent for cereals (25%), fruit (19%) and grape farms (16%). In particular, by looking at the (one) most important innovations, mechanical-automation and energy-water saving proves to be the most frequent with 32 and 20 replies out of 66 for cost reduction and 19 and 10 out of 56 for increasing production, respectively.

Beyond the motivations underlying the choice of the selected innovations, the survey investigated the selection and the adoption processes operated by the farmers. Indeed, farmers were asked whether they designed and/or developed the (adopted) innovation by themselves or obtained the information regarding the introduced innovations from external sources (and from whom the farmer was informed about the existence of such innovation).

In this respect, farmers who declare to have designed and/or developed the innovation by themselves are denominated "self-developers" and are considered to be the(ir) *internal source of information* as opposed to the other innovators who declared to have learned about the innovation from an *external source of information*.

The data about the sources of information, shown in Table 5, indicate self-developed innovation in the first column and the list of proposed external sources. Self-development of innovation has been declared by 31% of innovators, with prevalence for cereal, fruit and nursery farms. It follows that the remaining 69% learned about the innovation from external sources and, in particular, mostly from sources other than public institutions and unions/farmer associations. Indeed, 37% of the innovators declared to have acquired information about the innovation they decided to introduce from consultants, courses, local and visits to farms abroad. The second largest share is the 17% represented by the sources of information from people belonging to the sphere of personal relationships of the farmers such as friends, relatives and neighbours.

Unions and sectorial associations cover 10% of the external sources of information and the relative frequency appears to be uniformly distributed across specialisations. Only a residual share of about 2% represents the public institutions devoted to research and development in agriculture as the external sources of information. Such a result highlights the importance of intermediation between research and farmers.

As a follow up question, farmers were asked to declare their knowledge of the maker/producer of the innovation. By excluding self-developers, this inquiry reveals that most innovators (about two-thirds), who learnt about the existence of the introduced innovation from external sources, were also aware of who developed the innovation. This might indicate that farmers engage in a careful decision-making process before adopting the innovation or at least show a good level of awareness about its background. Qualitative

[4] The number of replies is greater than the number of adopters as the inquiry was devised as a multiple-choice question.

[5] The link was not explicitly asked, but, in the explicit list, we included the reduction of risks and the diversification of the activity in order to evaluate the motivations directly related to profitability. Very few replies were collected.

Table 5. Sources of information for innovation adopted per specialization.

Specialization	Self developed	External source of information				No reply	Total
		Institutions (University, Region, Province, Ministry)	Unions, associations	Acquaintances, friends, relatives, neighbours	Other sources (consultants, refresher courses/ trainings, visiting…)		
Milk-beef cattle							
Beef cattle	1			1	2		**4**
Milk cattle	3		2		2	2	**9**
Mixed cattle, mainly pastern	1						**1**
Ovine-caprine and pastern cattle					1		**1**
Cereal crops (wheat, maize, oats, barley)	**12**		3	6	**10**		**31**
Open field crops	2		1	1	4		**7**
Mixed crops							
Horticultural crops	2		2	2	3	1	**10**
High protein crops (grain pulses)				2	1		**3**
Combination of crops and cattle					1		**1**
Fruit	**9**	1	2	4	**9**		**25**
Olives					1		**1**
Grapes	3	1		2	**10**		**16**
Nursery	5		1	2			**8**
Non-classifiable			1		1	1	**3**
Total	**38**	**2**	**12**	**20**	**45**	**4**	121
	31.4%	1.7%	9.9%	16.5%	**37.2%**	3.3%	

Source: own elaboration on collected data.

additions during the interview revealed indeed that farmers rely upon trusted external sources of information and acquaintance with the producers[6,7]. Overall, the sample reveals that the majority of farmers either strictly rely on their own ability to develop an innovation or, on one's own initiative, search for information and cues from others' experience in order to make the best innovation choice and to meet their profit expectations.

In order to explore the connection between innovation adoption at farm level and research, farmers were asked to state whether they knew that the innovation they adopted originated from a specific agricultural research. This question was addressed only to those farmers that previously declared to have learned of the innovation through an external source of information. We excluded self-innovators from this question because we suppose that they engage in a process for introducing innovation that is mainly based on the self-development of their own ideas, which is completely different from the process followed by the other interviewed innovators. Hence, this question was asked to 83 innovators. Fifty-three respondents (about 64%) stated that they knew that the innovation was derived from specific research in agriculture. In particular, 29 out of these 53 (about 55%) concern mechanical innovations, mainly related to cereal, grape and fruit farms.

The stated effects on economic performance are reported in Figure 1. *Cost Reduction, Production Increase, and Value-Added Increase* are measured in per cent increase, while *Quality Increase* is measured through four categorical levels (not at all, low, high and very high) of increase due to the introduction of the innovation.

The number of observations of these variables does not correspond to the numerousness of the innovators' sub-sample (121), because not all respondents provided a reply to each of the four questions. Zero answers correspond to the actual observation of the performance by the farmer, while a missing reply might be justified by the lack of expectation, detection or perception of any impact on that specific component of profitability (in fact many farmers stated to not know the specific performance). Since the answers were not mutually exclusive, respondents had the choice to indicate more than one positive effect and potentially all of the four asked.

Cost Reduction (A), *Production Increase* (B), *Value-Added Increase* (C) show a noteworthy frequency of zeros; this was expected since it is unlikely that one innovation might yield positive profitability outcomes on all of the four considered components at the same time. The effect on *Cost* presents a concentration of positive outcomes within the range of 10-60% cost reduction (with the highest share on the lower boundary of the interval and no case recorded between 40% and 50%), while *Production* and *Value-added* are more frequently within the 10-40% interval of increase. *Production Increase* also shows a fairly high frequency around the 50-60% range. As far as *Quality increase* is concerned, it is observed that about 60% of the replies indicate an improvement in profitability due to high and very high quality increases, while only about 25% show no quality increases at all.

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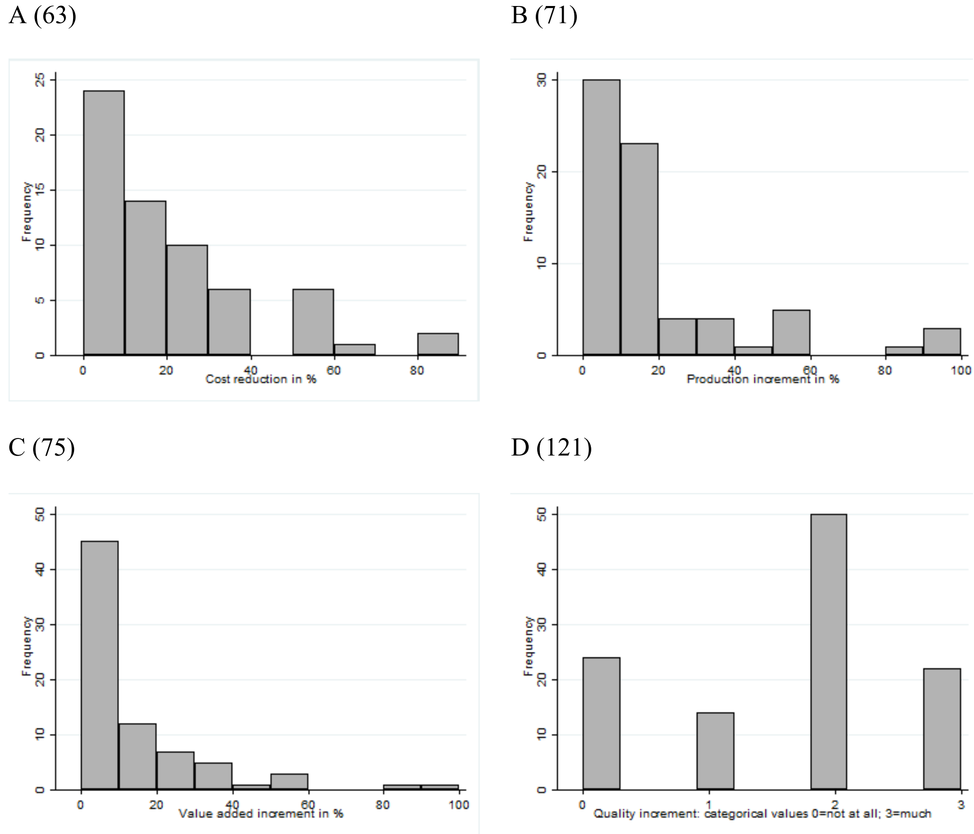
[6] For some types of innovation, such as mechanical ones, farmers have a better knowledge of the major brands/producers because of the presence, in the Emilia-Romagna region, of a large number of mechanical manufacturers that have been operating there since the beginning of the last century. Farmers in the Province of Bologna possess a deep knowledge of the evolution of mechanical technologies and mechanical manufacturing, which provides them with a sufficient ability to develop their own mechanical innovations.

[7] Detailed results are available from the authors upon request.

Figure 1. Frequency distribution of Cost Reduction (A), Production Increase (B), Value-Added Increase (C) and Quality Increase (D).



Source: own elaboration on collected data; number of observations in parentheses.

5.2 Econometric analysis

According with the methodology illustrated in section 3, the results obtained from the econometric analyses are reported in two groups: the first pertains to the adoption of innovation (adoption models) and the second concerns the linkage between adopted innovation and performance (performance models).

The results of the *Poisson* and *Probit adoption* models, shown in Table 6, indicate which factors are most important in determining respectively the number of innovations and the choice of (propensity to) introducing an innovation.

The ability of both models to analyse the survey data is quite good, as indicated by the Wald χ^2 statistics. The results from both models indicate that the propensity to innovate, in particular to adopt more than one innovation, is highly determined by the eco-

Table 6. *Poisson* and *Probit adoption* models.

Characteristics		Number of introduced innovations (Poisson)		Introduction of innovation (0-1) (Probit)	
		Coefficient	Marginal effect	Coefficient	Marginal effect
Innovation	Important innovations (last 20 yrs.)	0.91***	0.66***	0.78***	0.21***
Farm	Share of rented over total land	0.73***	0.53***	1.00***	0.26***
	Number of tractors	0.05***	0.03***	0.03	0.01
	Livestock specialisation	0.22	0.16	0.42	0.11
	Cereal specialisation	-0.54***	-0.39***	-0.59***	-0.16***
Socio-economic	Education > than mid-school	0.64***	0.47***	0.57***	0.15***
	Family income from Agric<30%	-0.58***	-0.42***	-0.53***	-0.14***
	Number of family labour	-0.16**	-0.11**	-0.11	-0.03
	Individual farm	-0.38*	-0.28*	-0.59***	-0.16***
	Constant	-0.70**			
	Observations	244		244	
	Wald χ^2	146***		80***	
	AIC	478.6		248.4	
	BIC	513.6		283.4	

Note: robust standard errors; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

nomic size and other structural characteristics of the farm, as well as by some individual and behavioural characteristics of the respondents. The positive role of the share of rented, over total, land may be connected to both the structural characteristics of the farm, likely qualified by a rent-based expansion, and to the overall size in terms of land area. The number of tractors is positively and significantly correlated to the number of innovations (but not to the decision to innovate) and shows that multiple innovations are more likely on large and capital-intensive farms. The positive and significant coefficient of the share of agricultural income shows a higher propensity to innovate on more professionally farms focused on agricultural activity. On the contrary, a higher number of family labourers and the juridical status of individual farms indicate that small farms are less inclined to adopt innovation (these are also correlated to the specialisation given the remarkable share of small cereal farms). As concerns individual and behavioural features, instead, we can observe that more educated farmers and those declaring that, in the last 20 years, important innovations in terms of profitability have been released show a higher propensity to innovate and, in particular, to adopt more than one innovation.

In order to further support these first results, and to better explain the process, a two-step model has been applied by employing a double-hurdle regression[8]. The results are shown in Table 7.

[8] Thanks to an anonymous referee for the suggestion of including a two-step model.

Table 7. *Double-Hurdle* model.

Characteristics		Number of introduced innovations
	Outcome (quantity) equation	
Farm	Number of tractors	0.09**
	Livestock specialisation	1.15**
	Cereal specialisation	-0.64*
	Fruit specialization, including grape and olives	0.29
Socio-economic	Specialised Ag education	-0.47*
	Family income from Ag <30%	-0.63**
	Family workers per ha	1.00*
	Constant	1.21**
	Choice (participation) equation	
Innovation	Important innovations in last 20 yrs	1.01***
Farm	Location: plain=1; hill=2; mountain=3	-0.22**
	Total Land	0.01***
Socio-economic	Education superior than middle school	0.75***
	Family workers per ha	-0.65**
	σ_Q	1.86***
	$\sigma_Q\sigma_P$	-1.69***
	Observations	245

Note: robust standard errors; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; σ_Q is the estimated value of the standard deviation of the error term of the quantity equation; $\sigma_Q\sigma_P$ is the estimated value of the covariance between the error terms of the quantity equation and the participation equation.

The results obtained through the double-hurdle model confirm those from the *Poisson* and the *Probit* models. In addition, they indicate that the choice of innovating depends highly upon location, especially in the plains and hills. Larger farms and higher education contribute to improve the probability of adoption. The consideration of *important innovations in the last 20 years* notably affects adoption, but it does not contribute to explain the number of adoptions. Moreover, what seems to determine increases in the number (quantity) of adoptions are factors related to the type of farming (and relative physical and economic size of the farm). In fact, larger farms with higher agricultural income, such as livestock farms, or farms with higher family labour and higher mechanisation (number of tractors) are more prone to adopt more than one innovation.

The core part of the analysis concerns the explanation of the economic performance of the adopted innovation, specifically in relation to its origin from research and in connection to the source of information. The results from the *probit performance* model concerning each of the four components of the farm's profitability are shown in Table 8.

Given the application of the *performance* models to each measure of performance, the number of observations for each group of regression is reduced with respect to the entire sample.

Table 8. *Probit performance* models.

Characteristics		Economic performance			
		Cost reduction [yes=1; no=0]	Production increment [yes=1; no=0]	Value added increment [yes=1; no=0]	Quality increment [very high, high=1; otherwise=0]
Innovation	Research-innovation link	0.21	0.77*	0.76*	0.83**
	Source of innovation [external=1; self =0]	-0.93	-1.22*	-1.59**	-0.87**
	Age of innovation	-0.01	0.04	0.06**	0.05*
	Important innovations (Last 20 years)	-0.73	-1.13**	0.05	-0.07
Farm	Cereal specialisation	0.65	0.53	-0.67	-0.05
	Share of rented land over total land	-0.42	-0.27	-0.42	0.18
Socio-economic	Individual farm [yes=1; no=0]	-0.20	0.11	0.67*	0.10
	Family income from Ag <30%	-0.91*	-1.72***	-1.37***	-0.32
	Education > than mid-school	0.34	-0.11	0.52	-0.28
	Constant	1.98**	1.88**	0.25	0.41
	Observations	50	56	62	88
	Pseudo R^2	0.176	0.245	0.317	0.115
	Wald χ^2	12.1	14.9*	30.4***	11.7
	AIC	71.7	76.6	78.7	123.9
	BIC	90.8	96.9	100.0	148.7

Note: robust standard errors; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The *probit performance* models applied on *cost reduction* and *quality improvement* proved to have a scarce capacity to explain the likelihood of obtaining positive performances. In the first model (*cost reduction*) only one regressor out of nine is significant and the sample is relatively small, while in the last model only the group of information variables contributes to explaining the variability in *quality improvement*.

On the contrary, the *probit performance* model proved to perform better when applied on *production* and *value-added increment*. In fact, for the latter models, the results show significant contributions in both groups of variables. From all significant results, a common pattern can be identified in the positive contribution of innovation originating from research, but also in the negative effect of *external information* on the likelihood of obtaining a positive economic performance.

These results indicate that farmers who knew the innovation from external sources have lower chances to obtain positive economic performance, especially in terms of *value-added* and *production*, with respect to *self-innovators*. On the other hand, the positive contribution of *research* on economic performance is more pronounced in terms of *quality*.

However, although the *probit performance* analysis provides interesting results, its specification might be affected, beyond the reduced number of observations, by selection bias in that only farmers who expect higher economic performance, on the basis of the information they possess, might decide to effectively adopt the innovation. In order to evaluate such a hypothesis, a *Heckit* model, specifically a *probit* model with sample selection, is run by formally dividing the variables into two groups, namely the selection (*adoption*) and outcome (*performance*) variables. The *Heckit* models indicate the presence of a self-selection process of innovation introduction related only to positive expected gains in *value-added*, as indicated by the significance of ρ, while the other model specifications indicate that both processes are essentially independent[9] (Table 9).

The results indicate that the *Heckit* models appear to be more appropriate in explaining the effects of the information variables on the economic performance. Indeed, these models, on one hand, confirm the results related to *research* and *source of information* from the previous *probit performance* models, and, on the other hand, report the same results as the *introduction* models, with the exception of the variable *number of tractors*.

6. Discussion

In this paper we investigate the determinants of innovation adoption and the relationship between origin of innovation and economic performance at farm level.

In the sample considered there is a noteworthy share of farmers who are actively innovating, which is partly explained by the long-time horizon taken into account. Most frequent innovations are in the field of mechanical innovations and innovation aimed at water-energy saving. This is consistent with the fact that mechanisation is a widespread need across farm specialisations, on the one hand, and with the current need to save resources in a context characterised by climate change; the latter issue is potentially emphasised by the location of the study area in a Mediterranean region. Multiple innovations are frequent among innovators, which may be explained by both the existence of connections among innovations (innovation packages) and the tendency of most active farm(er)s to innovate continuously (Läpple *et al.*, 2015).

The results from the adoption models, mainly testing the adoption determinants, are largely consistent with the findings in literature in terms of structural characteristics of the farms, such as farm size, mechanization, labour and production type, and subjective characteristics of the farmers, such as farmer education, experience and off-farm income[10]. The main novelty arises from the consideration of the judgement of farmers regarding the existence of important innovations in their field of specialisation, which helps to distinguish between cases in which the innovation choice by the farm results from the need of keeping up with a general technology shifts (i.e. replacing obsolescence), aligned to the *technological treadmill*, from cases in which innovation is more a choice tuned to the specific production and marketing needs of the farm. It also helps to understand the differ-

[9] Indeed, results were verified by running a *probit* regression on the performance variables by solely employing the information variables. The results confirm the ones obtained in the output equation of the *Heckit* model.

[10] The consistency of our results has been compared to the following literature: Feder and Slade, 1984; Lin, 2001; Daberkow *et al.*, 2003; Diederen *et al.*, 2003; Dimara *et al.*, 2003; Kounduri *et al.*, 2006; Cavallo *et al.*, 2014, Läpple *et al.*, 2015; Ramos-Sandoval *et al.*, 2018; Sauer *et al.*, 2019.

Table 9. *Probit performance* model with sample selection.

Characteristics		Economic performance: Cost reduction [yes=1; no=0]	Production increment [yes=1; no=0]	Value added increment [yes=1; no=0]	Quality increment [very high, high=1; otherwise=0]
	Outcome equation (O)				
Innovation	Research-innovation link	0.31	0.53	0.58*	0.79**
	Source of innovation [external=1; self =0]	-1.20*	-1.16**	-1.16***	-0.91**
	Age of innovation	-0.01	0.03	0.04	0.05*
	Constant	1.36**	0.98**	0.98**	0.30
	Selection equation (S)				
Innovation	Important innovations (last 20 years)	0.41*	0.48*	0.48**	0.84***
Farm	Breeder specialisation	0.52	-0.11	-0.20	0.56
	Cereal specialisation	-0.47**	-0.32	-0.64***	-0.52**
	Share of rented over total land	1.15***	0.76**	0.99***	1.03***
	Number of tractors	0.04	0.05	0.05	0.02
Socio-economic	Education > than mid-school	0.44*	0.49**	0.53***	0.52**
	Family income from Ag <30%	-0.22	-0.62***	-0.44**	-0.55***
	Family labour	-0.26**	-0.29***	-0.22**	-0.09
	Individual farm [yes=1; no=0]	-1.13***	-0.75***	-0.77***	-0.71***
	arctan(ρ)†	0.05	-0.27	-1.13*	-0.14
	Observations	241	243	240	232
	Uncensored Obs	50	56	62	88
	AIC	272.5	301.6	308.7	344.3
	BIC	321.3	350.5	357.4	392.5
	Wald χ^2 (O)	3.76	4.55	8.42**	10.2**

Note: robust standard errors; *t* statistics in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; † arctan(ρ) indicates the correlation coefficient between output and selection equations.

ent profiles of the non-innovators, namely those for whom no-innovation is linked to the absence of innovation in the sector in contrast to those foregoing innovation for personal or farm reasons, in spite of the progresses of innovations in the sector.

The second group of models, namely the *performance* models, represent, in our knowledge, the first attempt to evaluate the existence of a relationship between research and farm performance, also taking into account farmer intermediation. The first results support the hypothesis of a differential impact of innovations originating from research, which increase profitability by positively affecting value-added and quality improvements. On the contrary innovations originating from research do not appear connected to improvements in productivity or cost reduction.

Although this paper contributes to evidence on the role of research and information sources in improving farms' economic performance, it is also affected by some limitations that may affect the robustness and the generalisation potential of the results. First, the sample is rather small, in particular for the adopters' subsample, in particular considering the heterogeneity brought about by the large coverage of different farm specialisations. This may have contributed to the low significance of some of the models and some difficulty in estimation. This has also made potential additional explanatory variables difficult to use.

Second, the case study relies on a specific province in Italy, which, while benefiting from an internal heterogeneity (in terms of farm specialisation and altitude), still represents a specific context in terms of general ecological and legal conditions (including specific priorities e.g. for investment).

A third limitation concerns the way the data were collected. Due to a lack of better information availability (e.g. from accounting data) and resource limitations, most of the variables are based on statements made by farmers. This is a sensible topic, in particular with respect to the estimation of the impact of innovation on profitability parameters, which also implies a request for a difficult judgement on the part of the farmers, and of the origin of innovation, especially with respect to research, that incorporates a mix of actual information about the origin and level of documentation by the farmers. The origin of innovations and knowledge about it, in turn, relate to each other and are almost impossible to distinguish in the way in which the survey was run. Based on other questions and statements by farmers on their own level of information, we can interpret this information mostly as revealing the true origin of innovation, however there is certainly some level of (unmeasurable) approximation.

Fourth, and connected to the above, using stated information coupled with resource constraints implied the need to collect this information in a simplified way (e.g. using qualitative or dichotomous variables) and, in some cases, to use classes in the data treatment in order to account for "perceptive discontinuities" (such as round numbers in per cent statements). This, however, implies some further difficulty in the estimation and interpretation of the models.

These limitations, associated with the promising results achieved, highlight relevance and provide more precise hypotheses for further investigation on this issue. This would require, however, a larger sample, wider territorial coverage and would benefit from linkages to structural and performance data not available for this study.

An important message arising from the paper, in spite of the limitations, is that the role of farmers is crucial for innovation development and that farmers who are willing to innovate are engaged in a continuous learning process which includes, beyond the practical knowledge of the available innovations, the knowledge and awareness of the process leading from research to the realisation of the innovation as well. This evidence supports the paradigmatic change of the innovation process from AKS towards the AKIS and multi-actor concepts (SCAR, 2012), by providing additional insight into the proactive role of farmers in the management of external information coming from different sources, including research, and of own-knowledge within the innovation adoption process (Klerkx *et al.*, 2009; Läpple *et al.*, 2015). Such proactivity might represent a relative competitive advantage for the improvement of farm performance and a key feature of entrepreneurship. However, its 'anatomy' would need to be better analysed in future studies, with the collection of more specific information about on-farm processes leading to innovation adoption or implementation on the farm.

7. Conclusions

The results of this paper show the importance of innovation for a large share of farms, considering a substantial time frame of 20 years. Most frequent innovations are in the field of mechanical innovations and innovation aimed at water-energy saving. Multiple innovations are frequent among innovators.

Classical factors, such as proxies related to farm size, remain the most suited variables to explain the adoption of innovations, while motivations for innovation adoption are largely related to the combination of cost reduction and production increases.

The process of innovation development and adoption follows two main pathways: self-development by farmers and development by mostly private companies. Agricultural research is generally known to be in the background, but rarely seems to lead directly to technology development and even less to adoption. This may also be connected to the prevailing technologies that are considered to be relevant in the area (mechanisation and water/energy saving), which require important steps in terms of 'engineerisation' of knowledge and fine tuning in local conditions (including machinery set-up and feedback from users). In either case, the mediation between research and farmers has an important industry component or, in any case, involves different layers of actors.

The (knowledge of) existence of research activities in developing the innovation seems to be associated to better performance only for the specific but important cases of improving the value-added and of achieving very high-quality production. This suggests that scientific research can have a specific role in terms of different performance-improving strategies, and, in particular, that it can contribute comparatively more to quality, while self-development or industry-led technology adaptation can have a better role in cost reduction.

These results also yield relevant insights in terms of research policy. In particular, when promoting multi-actor approaches, innovation policies should better consider different regional/sector objectives in terms of quality, productivity or cost reduction, and related to this, more explicitly evaluate the potentially different roles of private and public research and innovation players. In addition, while it can be expected that economic incentives linked to factor and product prices mainly affect cost reduction through self-innovation, a stronger role has anyway to be attributed to direct research and innovation incentives if quality objectives are to be pursued.

In spite of its limitations, the study hints at the need to further explore the co-existence and interplay among different innovations, different innovation pathways and different innovation impacts. Moreover, the interaction between awareness of technology development pathways and actual technology performance at farm level is an issue that was only partially untangled in this paper and one that is undoubtedly worthy of further investigation.

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Annex

	Obs	Mean	Std. Dev.	Min	Max
Structural data					
Zootechnics specialisation	300	0.08	0.26	0	1
Fruit specialisation, including grape and olives	300	0.26	0.44	0	1
Cereal specialisation	300	0.40	0.49	0	1
Protein crop specialisation	300	0.06	0.23	0	1
Arable crop specialisation, including horticultural crops	300	0.62	0.49	0	1
Presence of ancillary activity: yes=1; no=0	300	0.26	0.44	0	1

	Obs	Mean	Std. Dev.	Min	Max
Sale contracts	300	0.33	0.47	0	1
Share of rented land over total land	300	0.20	0.30	0	1
Own land	300	17.03	27.82	0	300
Rented land	300	9.72	25.11	0	200
Total Land	300	26.75	45.67	0	500
Number of tractors	300	3.43	2.83	0	20
Number of operational machines	300	3.15	2.32	0	9
Demographic data					
Individual farm: yes=1; no=0	300	0.80	0.40	0	1
Family farm: yes=1; no=0	300	0.96	0.20	0	1
Family labour	285	1.89	1.09	0	7
Family labour Full Time	285	1.35	0.89	0	6
Family labour Part Time	285	0.54	0.86	0	4
Education inferior than medium school =1	300	0.22	0.41	0	1
Education superior than elementary school =1	300	0.73	0.45	0	1
Education superior than high schoo l=1	300	0.09	0.29	0	1
Specialized Ag education =1	300	0.46	0.50	0	1
Family income from Ag <30% =1	142	0.55	0.50	0	1
Family income from Ag <50% =1	176	0.69	0.46	0	1
Considerations					
Important innovations in last 20 years: yes=1; no=0	300	0.47	0.50	0	1
Continue farming in 5 years: yes=3; maybe yes=2; maybe no=1; no=0	277	2.36	0.79	0	3
Introduce innovation in next 5 years: yes=1; no=0	176	0.35	0.48	0	1
Innovation important for competitiveness: not at all=0; little=1; enough=2; much=3	272	2.42	0.72	0	3
CAP help innovation adoption: not at all=0; little=1; enough=2; much=3	248	1.57	1.00	0	3
CAP necessary for supporting agriculture: not at all=0; little=1; enough=2; much=3	267	2.19	0.97	0	3
Description of data for non-innovators (reasons for not innovating)					
No introduction = 1	300	0.60	0.49	0	1
No introduction for high costs = 1	179	0.47	0.50	0	1
No introduction for ethical reasons = 1	179	0.01	0.11	0	1
No introduction for too bureaucracy = 1	179	0.05	0.22	0	1
No introduction for high risks = 1	179	0.06	0.23	0	1
No introduction for quitting activity soon = 1	179	0.09	0.29	0	1
No introduction for negative past experiences = 1	179	0.02	0.13	0	1
No introduction for keeping traditions = 1	179	0.10	0.30	0	1
No introduction for other reasons = 1	179	0.28	0.45	0	1
Description of data for the subsample of innovators					
Number of introduced innovations	300	0.71	1.16	0	8
Introduction of innovation: yes=1; no=0	300	0.40	0.49	0	1

	Obs	Mean	Std. Dev.	Min	Max
Year of introduction of the innovation	109	2007	6.01	1995	2015
Age of innovation wrt to introduction	109	8.03	6.01	0	20
Intro for reducing risks = 1	121	0.11	0.31	0	1
Intro for diversifying ag activity = 1	121	0.14	0.35	0	1
Intro for reducing costs = 1	121	0.55	0.50	0	1
Intro for increasing production = 1	121	0.46	0.50	0	1
Other reasons (most increasing profitability and reducing labour)	121	0.27	0.45	0	1
Reaction to increase in input prices	121	0.49	0.50	0	1
Reaction to reduction in output prices	121	0.52	0.50	0	1
Anticipate inputs markets trend	121	0.36	0.48	0	1
Anticipate outputs markets trend	121	0.37	0.49	0	1
External help from private or seller	120	0.37	0.48	0	1
External help from public institutions	120	0.01	0.09	0	1
No external financial support for introducing innovation	120	0.56	0.50	0	1
Level of self-financing: 0=less than 5.000; 3=more than 50.000	91	1.85	1.10	0	3
Type of innovations					
Biological and Genetic innovations	121	0.07	0.25	0	1
Agronomical and Zoological innovations	121	0.06	0.23	0	1
Mechanical innovations	121	0.37	0.49	0	1
Informatics innovations	121	0.02	0.13	0	1
Energy and water saving innovations	121	0.22	0.42	0	1
Diversification innovation	121	0.12	0.33	0	1
Market strategies innovations	121	0.02	0.13	0	1
Information about origin of innovation					
Source of information about innovation: external=1; self produced=0	121	0.69	0.47	0	1
Knowledge of innovation origin from research	121	0.44	0.50	0	1
Effects of introduced innovation on economic performance					
All effects: presence of (positive) effect=1; otherwise=0	121	0.87	0.34	0	1
Cost reduction in %	63	17.81	20.94	0	90
Cost reduction: yes=1; no=0	63	0.71	0.46	0	1
Production increment in %	71	16.17	24.02	0	100
Production increment: yes=1; no=0	71	0.65	0.48	0	1
Value added increment in %	75	11.20	18.56	0	100
Value added increment: yes=1; no=0	75	0.52	0.50	0	1
Quality increment >0: very high, high and low=1; nothing=0	121	0.80	0.40	0	1
Quality increment >1: very high, high=1; otherwise=0	121	0.60	0.49	0	1
Quality increment: not at all=0; little=1; enough=2; much=3	110	1.64	1.04	0	3