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A duration analysis of on-farm agrobiodiversity conservation: Evidence from Portuguese fruit growers

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Abstract

We investigate the factors that influence farmers' adoption of agrobiodiversity measures using survey data collected at a geographically relevant scale. The current economic theory of technology adoption is used to guide our thinking. While, to date, studies in this area have frequently employed standard probit/logit techniques, we adopt an econometric technique that addresses simultaneously the issue of sample censoring, temporal dependence and the joint determination of the occurrence and timing of adoptions. The use of more appropriate techniques to the analysis of adoption data uncovers a sizably higher effect of information on farmers' decisions than that obtained by standard discrete-choice approaches. The result is an affirmation that good extension services providing reliable and accessible information, as well as technical guidance adapted to local conditions, are fundamental components to effect the adoption of resource-conserving measures.

Keywords: Agrobiodiversity, duration analysis, adoption models
JEL Classification: C41, O33, Q16, Q18, Q57, Q58

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1. Introduction

It is widely recognized that the conservation of agricultural biodiversity, or agrobiodiversity, is of paramount importance to secure a sustainable agriculture, food production, and environmental conservation.[1] The dramatic loss in agrobiodiversity observed worldwide over the past decades led to FAO's International Technical Conference on Plant Genetic Resources held in Leipzig, Germany in June 1996. At this conference, a Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture was adopted by 150 countries, emphasizing the important role of *in situ* conservation and on-farm management in harmony with the Convention on Biological Diversity (CBD).[2]

More recently, the International Treaty on Plant Genetic Resources for Food and Agriculture, which was adopted by the FAO Conference on November 2001 and entered into force on June 2004, clearly highlights the fundamental role played by *farmers* in the preservation and promotion of traditional practices that conserve and maintain agrobiodiversity.[3]

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[1] Agrobiodiversity may be regarded as a subset (and an extension) of biodiversity, and may be roughly defined as the number and composition of species cultivated and grown by farmers. Briefly, the conservation of agrobiodiversity may be carried out through the conservation of genetic resources in genebanks, a method known as *ex situ* conservation. With this method, genetic resources are to be kept unchanged as far as possible. Another conservation method is known as *in situ* conservation, whereby genetic resources are conserved in their natural habitat, and are, therefore, subject to changing environmental conditions and may adapt to them. Along with these methods, on-farm management also aims at conserving or further developing agrobiodiversity. On-farm management takes place within farms, and is particularly relevant when it is not possible to secure protection areas for crop plants requiring human care.

[2] The Convention on Biological Diversity was adopted at the UN Conference on Environment and Development held in June 1992 in Rio de Janeiro, Brazil. The Convention places agricultural genetic resources as part of the total biodiversity under the responsibility of the signatory countries, requiring from them the conservation, sustainable use and fair distribution of the benefits that arise from the use of genetic resources.

[3] Amongst other provisions, this Treaty establishes a bundle of farmers' rights including the "protection of traditional knowledge relevant to plant genetic resources for food and agriculture". Although there are several initiatives in this field, the only specific legislation measure that exists so far within the European Union concerning traditional and local knowledge is the Portuguese Decree-Law No. 118/2002. Recognizing the contribution made by the local farming communities to agrobiodiversity conservation, this unique Law confers upon farmers particularly tailored exclusive rights in their traditional knowledge and practices.

Within the European Union (EU), the policy determination to promote agrobiodiversity has been mainly addressed through the implementation of specific agri-environmental policy measures.[4] In Portugal, one of such measures consisted in the protection of *regional varieties of fruit trees*, but due to farmers' weak response, it was most recently abandoned. This is problematic for several reasons. First, according to the IUCN Red List of Threatened Species (IUCN, 2007) Portugal is the European country with the second highest number of endangered and vulnerable plant and animal species (following Spain). Considering plant species only, Portugal remains the European country with the second highest number of endangered, vulnerable and conservation dependent species. Secondly, given that agri-environmental measures are the most relevant policy tool for biodiversity conservation on farmland within the EU countries (European Environment Agency, 2007), the objective of halting biodiversity loss is critically compromised if EU farmers do not respond positively to such measures. Third, the weak response of farmers to these measures reveals that in spite of the political pressures, and the increasing general awareness of the importance of *in situ* and on-farm conservation of agrobiodiversity, there is still limited knowledge about the factors that influence farmers' management of diversity.

In fact, as the foregoing discussion shows, the current national and international political agenda poses complex choices for farmers: they must meet increasing demands for food, be nationally and internationally competitive, while, at the same time, be active actors in the conservation of *in situ* and on-farm biodiversity. On an historical perspective, these are seemingly conflicting objectives as the intensification of agriculture brought about by the former is often considered a major cause of agrobiodiversity loss. In addition, as pointed out by Smale and Bellon (1999), preserving biodiversity is not a moral obligation of farmers. If the policy goal is the preservation of genetic resources in

[4] The agri-environmental measures established within the Common Agricultural Policy (CAP) to protect and improve the environment are essentially defined in the EC Council Regulation 2078/92.

agricultural areas, namely through farmers' adoption of agri-environmental measures aiming at local crop systems' conservation, then this option must be advantageous to farmers vis-à-vis other options they might have. Farmers must be provided with economic, cultural, ecolological, or other relevant incentives to maintain those varieties that are considered important genetic resources.[5]

The purpose of this paper is to contribute to a better understanding of the factors that influence farmers' adoption of traditional varieties of fruit trees so that better and more effective policy measures aiming at their preservation can be designed and implemented. The study focuses on a particular apple variety, called *Bravo de Esmolfe*, originated in the interior central region of Portugal[6] which, due to its genetic and local value, was given the title of Protected Designation of Origin.[7] However, the proportion of *Bravo de Esmolfe* in the total apple production in the region is relatively small.[8] Our empirical approach is based on the assumption that the adoption of traditional plant genetic resources can be treated as a technological innovation, and, therefore, subject to the same rules and processes that characterize the adoption and diffusion of other

[5] There is now a considerable body of literature on the economic theory of technology adoption. An important line of inquiry in this literature focuses on the factors affecting individual adoption, as distinguished from aggregate adoption. Briefly, the current economic theory of adoption at the individual (farmer) level posits that the potential adopters make their choices based on the maximization of expected utility subject to prices, personal characteristics, natural resource assets, and policies. See, for example, Feder *et al.* (1985) for a survey of theoretical and empirical studies on the adoption of agricultural innovations, and Stoneman and David (1986) on government policies aiming at increasing the take up of new technologies.

[6]More specifically, it is originated in the Viseu area and is disseminated by several municipalities in the regions of Beira Alta and Beira Baixa. While the literature looking at the preservation of traditional plant varieties is mostly focused on the behavior of rural populations in developing countries (Altieri and Merrick, 1987; Brush *et al.*, 1992; Epperson *et al.*, 1997; Heisey *et al.*, 1997), and in areas with intensive agricultural practices (Dimara and Skuras, 1998; Brennan *et al.*, 1999), the growing concern over agrobiodiversity loss in developed countries justifies a closer look at farmers' management of diversity in these countries.

[7] A Protected Designation of Origin (PDO) is a name defined in the European Union legislation enacted in 1992 to protect the reputation of the regional foods, eliminating the commerce of non-genuine products that may be of inferior quality.

[8] According to information available online at the site of the Policy and Planning Office of the Portuguese Ministry of Agriculture, Rural Development and Fisheries (www.gppaa.min-agricultura.pt; *Diagnósticos Sectoriais*; *Maçã*), the variety *Bravo de Esmolfe* represented 7% of the total apple production in the region in 2005, while the varieties *Golden Delicious*, *Red Delicious/Starking*, and *Galas* represented 46%, 34% and 8%, respectively (the remaining 5% were spread across several types of apple).

innovations.[9] We employ an econometric technique that allows us to control for both the occurrence and the timing of adoptions, while taking into account the censored nature of adoption data and its temporal dependency, and that, to the best of our knowledge, has only been previously used by Fuglie and Kascak (2001) and Burton *et al.* (2003) in the empirical literature looking at the adoption of agricultural technologies and practices in developed countries.

The paper proceeds as follows. Section 2 sets out the empirical model and the estimation methods used. Section 3 presents the sample and the variables used in the analysis. Empirical results are provided in section 4. A discussion and conclusions are contained in Section 5, along with comments on study limitations.

2. Empirical Framework

The empirical research on the adoption of new agricultural technologies has frequently relied on probit (Klotz *et al.*, 1995; Negatu and Parikh, 1999, Faria *et al.*, 2002; Foltz and Chang, 2002) or logit models (Caffey and Kazmierczack, 1994; Dimara and Skuras, 1998; Bartoloni and Baussola, 2001; Somda *et al.*, 2002) that estimate the probability of adoption at a moment in time as a function of a set of explanatory variables expected to be relevant to the "adoption or non-adoption" decision.[10] In their standard forms, these static models of adoption do not allow for different rates of adoption over time. However, as emphasized by Burton *et al.* (2003), the important question in a technology adoption study is to determine the probability that a firm adopts a technology immediately after moment *t*, given that it has not adopted the technology until that moment. Duration analysis is the most appropriate econometric tool to address

[9] The adoption of a technological innovation in agriculture may be taken as a broad concept, encompassing both new and existing biological, chemical, and mechanical techniques, along with new and existing farming practices. Using the current economic theory of innovation adoption and diffusion in this context is increasingly appropriate given that, as pointed out by Hooks *et al.* (1983), many extension services currently aim at promoting the revitalization of traditional plant varieties, and at the adoption of long existing agricultural technologies and farming practices, rather than the strict adoption of new innovations.

[10] Other less frequently used modeling techniques include multiequation modeling (see Feder *et al.* (1985) for a review), Tobit models (see Adesina and Baidu-Forson (1995) for an application), etc.

this question empirically.[11] In addition, from a methodological point of view, the duration approach is a superior method of dealing with the dynamic nature of adoption data than the standard probit or logit models, allowing prompt corrections for censoring, heterogeneity and duration dependence. Censoring, or more specifically *right censoring*, is a form of incomplete observation for those individuals who have not experienced the event of interest by the end of the observation period.[12] Heterogeneity is a result of incomplete control occurring if some relevant explanatory variables are left out, the functional form is misspecified, or unobservable variables are important, all of which violate the assumption that the distribution of the dependent variable across individuals is homogeneous. Duration dependence occurs when the risk of an individual or firm adopting a technology depends on how long it has been in a non-adopting state. In contrast to duration models, the standard probit/logit approaches fail to account for duration dependency, potentially resulting in misleading inferences.[13]

Duration models focus on the length of time that a firm or an individual stays in a particular state before leaving that state. The fundamental concept in this methodology is the probability that an event occurs at a specific moment, given that it has not yet occurred. The methodology is therefore particularly useful in adoption studies because it not only allows the determination of the probability that an individual adopts a technology up to a specific moment in time, but also the expected diffusion rate of the

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[11] Duration analysis, also generally known as survival analysis, was first applied in the medical sciences to study the time span between a surgery and death, for example, as well as in engineering (where it is most commonly known as reliability analysis) to study the time span between the production of a given product and its failure. Lancaster (1972) study on unemployment is often cited as the first application of duration analysis in economics. Recent reviews of applied duration analysis can be found in Hougaard (2000) and Therneau and Grambsch (2000), and its application to economics has been developed in detail by Lancaster (1990). Hannan and McDowell (1987), Levin *et al.* (1987), Karshenas and Stoneman (1993), Fuglie and Kascak (2001), and Burton *et al.* (2003) are examples of applications of duration analysis to technological adoption.

[12] Strictly speaking, duration data may be right and/or left censored. Left censoring arises when the length of an interval is known to be *less* than some value although the exact length is unknown. Right censoring arises when the length of an interval is known to be *greater* than some value although the exact length is unknown. The intervals for the adoption data under discussion are right, rather than left, censored.

[13] This discussion assumes standard probit/logit models unmodified by spline functions which, when applied to temporally dependent data, can result in overly optimistic inferences, ie, inflated t-values due to substantially underestimated variability (Beck *et al.* (1998)).

technology, considering that the entire population of potential adopters is present at the moment the technology becomes available. In addition, when explanatory variables are included, it is also possible to determine the sign and magnitude of the effects of these variables on the length of time until an event occurs. Consequently, duration analysis allows the study of both technological adoption and diffusion phenomena simultaneously.

Duration models in this context are formalized by first specifying a probability density function $f(t)$ for the duration of the non-adoption state. Although this unconditional density function is the fundamental element in duration models, it is a conditional density function known as the hazard function that is more useful in our analysis. The hazard function is given by $h(t)=f(t)/[1-F(t)]$, where $F(t)$ is the corresponding cumulative density function of t.[14] This function gives the probability of adoption at time t given that the non-adoption state has lasted until time t, and therefore it constitutes the basis to directly address the important question in this study: what is the probability that a farmer who hasn't adopted a regional variety of fruit trees will do so at a certain point in time.[15]

When the objective of the analysis is to examine the effect of explanatory variables on the duration phenomenon, the so-called proportional hazards model is the most often used. This model specifies the hazard function as $h_i(t)=h_0(t)exp(\beta' x_i)$, where $\beta' x_i$ is the matrix of coefficients and explanatory variables for the i[th] individual. In this

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[14] The expression $[1-F(t)]$ is known as the survival function and gives the probability that an individual remains in the non-adoption state at least up to time t. Both the survival function and the hazard function are mathematically derived from the duration density function $f(t)$, and, consequently, do not alter the nature of the model.

[15] More precisely, this definition of the hazard function applies only when we are dealing with discrete time. Although in practice time is always measured in discrete units, however small, it is usually treated as if measured on a continuous scale, an acceptable practice as long as the time of event occurrence is measured exactly. The definition of the hazard function in continuous time must change, however, because the probability that an event occurs at exactly time t is infinitesimal for every t. Specifically, the hazard in continuous time assesses the conditional *risk* at time t that an individual who has not yet done so will experience the event. Thus, although it may be useful to think of the hazard function in continuous time as the conditional instantaneous probability of event occurrence, it is more properly interpreted as a *rate per unit time* rather than as a probability because it can be greater than 1.

specification, the hazard function is a multiplicative function of two separate components. The first component, *$h_0(t)$*, is known as the baseline hazard and is a function of duration time only. It can be thought as the time path that durations follow if the effects of all covariates are zero, reflecting, therefore, time dependence (or independence). The second component takes the exponential form, and is a function of explanatory variables other than time.[16] Since duration time is separated from the explanatory variables, the hazard function is obtained by simply moving the baseline hazard as the covariates change, so that it is proportional to the baseline hazard for all individuals. This means that each individual's hazard function follows exactly the same pattern over time, but there is no restriction on what this pattern can be.[17] The above specification can be easily extended to allow for time-varying covariates. As the name suggests, a covariate is time-varying if its value changes over the course of durations. When such covariates are introduced in the model, however, the hazards cease to be proportional since $h(t)/h_0(t)$ varies over time along with the values of the time-varying covariates $x(t)$.

Estimation of duration models may be carried out through non-parametric, semi-parametric, or parametric methods. Non-parametric methods are simple to apply, and do not require any assumption about the functional from of the duration density. However, these methods do not incorporate the effects of explanatory variables. The Kaplan-Meier (1958) estimator of the survival function is amongst the most often used non-parametric method in duration analysis. The Kaplan-Meier estimator of the survival function

[16] The exponential functional form is adopted to guarantee that the hazard function is well-behaved. In our analysis, the adoption of this functional form ensures that the estimates of the transition probabilities from non-adopter to adopter of the regional variety *Bravo de Esmolfe* are non-negative.

[17] There are several approaches to test for the appropriateness of the proportional hazards assumption embedded in this specification. One popular approach consists in including an interaction term as an explanatory variable $x_2=x_1t$, where x_1 is already in the model, and verify that the interacted variables have no significant effect. Another popular test is based on scaled Schoenfeld residuals. This test is fully documented in Grambsch and Therneau (1994), and is based on the idea that the logarithm of the hazard ratio function as computed nonparametrically by the Schoenfeld residuals should be constant over time (ie, have zero slope when plotted against functions of time) if the proportionality assumption is valid.

estimates non-parametrically the probability of surviving past time j. Let n_j stand for the risk set or number of potential adopters at the beginning of time j, and d_j be the number of adoptions at time j. Then $p_j=(n_j-d_j)/n_j$ is the proportion of no-adopters at the end of time j, and the Kaplan-Meier estimate of the survival function is given by $\hat{S}(t)=\prod_{j|t_j < t\,(p_j)}(p_j)$, where the product is taken over all observed adoptions less than or equal to t. A popular semi-parametric method is Cox's (1972) proportional hazard model which allows the estimation of the effects of covariates on the hazard function, but leaves unspecified the functional form of the baseline hazard. Cox's model is therefore very useful when the analysts have no prior expectations concerning the nature of the duration process.

Parametric methods require the specification of the functional form of the baseline hazard. The most popular specifications in economic applications are the exponential and the Weibull densities, although any distribution for a nonnegative random variable may be chosen. The exponential density is given by $f(t)=\delta\exp(-\delta t)$ where $\delta>0$. In this case, $F(t)=1-\exp(-\delta t)$, and the hazard function is a constant equal to δ, meaning that the hazard rate is invariant to time. The Weibull density is a generalization of the exponential given by $f(t)=\gamma a t^{a-1}\exp(-\gamma t^{a})$, and the hazard function is equal to $\gamma a t^{a-1}$ where the parameters γ,a are positive. In this case, the Weibull becomes the exponential if a=1; if a>1 the hazard function is monotonically increasing over the duration, and it is monotonically decreasing if a<1. When the baseline hazard is correctly specified, these methods produce more efficient estimates of the covariates' coefficients than the semi-parametric methods. On the other hand, if the form of duration dependency is incorrectly specified, the inferences generated from parametric methods can be misleading (Collet (1994), Bergström and Edin (1992)). There are several theoretical models in the technology adoption literature focusing explicitly on the time taken to adopt;[18] however they do not indicate any specific functional form for the distribution of the durations.

In our analysis, we opt for non-parametric procedures to have an assessment of the survival times of all the individuals in the sample. Because we have no prior expectations about the nature of the baseline hazard function, we rely on the semi-parametric Cox model for the multivariable analysis, but for completeness and comparison purposes the results of parametric estimations are also reported.

3. The Sample and Selection of Variables

A. The Sample

Personal structured interviews were conducted between November 2004 and February 2005 with fruit growers located in the production area of the *Bravo de Esmolfe* apple to obtain the data used in the analysis.[19] All the respondents were selected among the members of the Agricultural Cooperative of Mangualde (CAM) because virtually all of the apple producers in this region market their production through this Cooperative.[20] To further ensure that the sample is composed of established apple producers, only those producers who delivered apple to CAM in the 2003-2004 crop, and who exploit a continuous area of apple trees higher than 0.1 hectare were selected for the interviews.

The data collection process in the field started by contacting each farmer by phone informing them about the objectives and scope of this research, and enquiring them about their willingness to participate in a survey. To ensure credibility, the involvement of CAM and its technician was mentioned in all contacts. Out of the total of 99 fruit producers selected according to the above criteria, 17 were eliminated from the

[18] See, for example, Hiebert (1974), Lindner *et al.* (1979), Feder and O'Mara (1982), Feder and Slade (1984) for models based on learning, beliefs and information acquisition, and Dixit and Pindyck (1994), and Carey and Zilberman (2002) for approaches based on real option theory.

[19] The survey is available from the authors upon request. The same author (Dinis) conducted all the personal interviews to ensure comparability.

[20] Other important Cooperatives for the producers in the region are the Viseu and Távora Cooperatives, but CAM is the most important one for these producers.

sample because it was not possible to reach them in this initial contact and, from those contacted, 7 declared to be unwilling to participate. A new phone contact was made with the remaining 75 fruit producers to schedule the date, time and place for the interview.[21]

The survey was composed of seven groups of questions. The first group of questions intended to characterize the producer and his family unit. Within this group, we collected information on sex, age, years of experience in the activity, and years of schooling of the farmer and household members. Farmers were also questioned on the number of hours spent by themselves and their household members on the farm, the kind of activities performed by each member on the farm, and outside of the farm. Additionally, information on the amount and sources of income earned by the household was also collected.

The second group of questions intended to characterize the farm: location, type of management, labour force, total dimension, producing activities performed in the farm and the size of each activity. Within this group, information about the quantity produced, sales price, and variable costs of each producing activity was also collected. All the questions related to the production of apples were posed by apple variety. The third group of questions focused on fruit production in more detail. Information was collected concerning the installation dates of the fruit production activity as well as the date when the production of the variety *Bravo de Esmolfe* was initiated. Farmers were also questioned about the reasons behind the decision to adopt or not this apple variety. Additionally, the survey included questions on the type of technologies used, watering mechanisms, fertilization, etc.

[21] Based on a comprehensive survey of Portuguese fruit growers undertaken in 2002, the Portuguese National Statistical Institute (www.ine.pt) estimated that the production of the variety *Bravo de Esmolfe* accounted for 10% of the total apple area in the production regions of this variety. The percentage of total apple area dedicated to the production of the variety *Bravo de Esmolfe* as reported by the producers included in the sample is 14% as of 2005, a figure that sits well with the estimated 10% in 2002 given the increase in area that production of this variety has been registering (INE (1998, 2002)).

The fourth group of questions intended to elicit farmers' attitude towards the environment. In particular, farmers were asked whether they were members of any environmental organization, whether they used agricultural practices usually classified as environmentally friendly, and what was their opinion about the relationship between agriculture and environmental preservation. The latter was included in the survey in order to uncover whether farmers followed what Beus and Dunlap (1990; 1991) refer to as the traditional agriculture paradigm or the sustainable agriculture paradigm. To this end, we built a table of 15 questions adapted from Beus and Dunlap (1991) and Comer *et al.* (1999), asking respondents to express their agreement or disagreement, on a 1 to 5 scale, with each statement.

The purpose of the fifth group of questions was to uncover farmers' relation to the European Union Agricultural Policy. This group of questions focused on the use of European Union's funds for investments on the farm, and on the type of direct assistance received. The sixth group of questions asked farmers about the sources of information they used to develop their activities. The aim of these questions was to understand which channels of information were more useful for farmers. A final group of questions was included in order to elicit farmers' perceptions towards the variety *Bravo de Esmolfe*. To this end, farmers were presented with a list of twelve statements attributing advantages and disadvantages to this variety relatively to other varieties, and asked to express their agreement or disagreement, on a 1 to 5 scale, with each statement. All the twelve statements were formulated based on opinions and technical information collected from farmers and technicians previously to the design of the survey instrument.

B. Selection of Variables

The dependent variable in duration models is treated as a temporal variable. Its definition requires the determination of a moment of origin, a temporal scale, and the characterization of the event that determines the end. In this study, the temporal scale adopted is annual since the plantation of fruit trees depends on weather conditions that occur only for a short number of months within a year, and after this period is passed it is necessary to wait for the subsequent year to have the opportunity to plant again. The moment of origin, or starting date, is the year of the first plantation of fruit trees since it corresponds to the date when the farmer first had to consider the possibility of introducing the *Bravo de Esmolfe* variety in his plantation. The event that determines the end of the duration process is the adoption of the *Bravo de Esmolfe* variety.[22] Because we are dealing with the adoption of a traditional fruit tree, it is possible that this particular variety is present in some farms not as a result of a deliberate decision from the farmers to adopt it but because it was left by previous generations. Thus, to ensure that the end event is properly identified, the adoption year for any given farmer is taken as the year the farmer starts exploring a continuous area of *Bravo de Esmolfe* of at least 0.1 hectare.

Selection of the independent variables in the estimated duration models is driven by theoretical considerations, and previous research findings. The adoption of agricultural varieties is thought to depend on a number of factors that, in the discussion below, fall under the headings of *Characteristics of Farmers*, *Characteristics of Farms*, and *Perceptions and Agricultural Practices.*

[22] In other words, the "response" variable in duration models is constituted by the triple (t_0, t, d), where t_0 and t mark, respectively, the beginning and the end of a time span in analysis time units, and d indicates the outcome (adoption or censoring) at the end of each time span. Irrespective of the particular analysis time units under consideration, a question might arise as to how to handle "failures" (or "adoptions" in this application) that occur at the onset of risk or, more generally, how to handle a censoring that happens at the same time as a failure. A common convention is to assume that failures occur before censorings (and that failures only occur after the onset of risk) by defining a time span to be the interval $(t_0, t]$ which is open at t_0 and closed at t. Thus, under this definition, a censored failure at t is thought of as instead being censored at some time $t+\varepsilon$ for an arbitrarily small ε, so that failures occur before censorings. This convention is followed by the Stata software that is used for all the computations in this paper. Version 9.0 of this software is documented in StataCorp (2005), and Cleves *et al.* (2004) provide a useful introduction to duration analysis using Stata.

Characteristics of Farmers

The theory of technology adoption in agriculture posits that farmers' human and social capital characteristics are important determinants of adoption decisions. Human capital is frequently measured by farmers' age, schooling, and years of experience. Because older farmers are expected to be less receptive to change, the variable age is expected to lower the likelihood of adopting new agricultural practices or technologies (Gasson, 1988; Shucksmith and Smith, 1991; Dimara and Skuras, 1998). As pointed out by Khanna *et al.* (1999), years of experience are also expected to exert a negative effect on the likelihood of adoption as individuals' knowledge of previous practices or technologies is more established, and, consequently, they may be more reluctant to invest time and effort in acquiring the needed knowledge to successfully implement different practices or technologies. The effect of education on the likelihood of adoption is expected to be positive since many empirical findings suggest that farmers with a higher education level adopt new technologies sooner, and are able to extract more benefits from the adoption (Rahm and Huffman, 1984; Feder *et al.*, 1985; Khanna *et al.*, 1999; Brush *et al.*, 1992; Klotz *et al.*, 1995).

The opportunity to earn income outside of the farm is another variable often referred to as an important determinant of adoption decisions, although the direction of its effect is unclear. On the one hand, it may facilitate the adoption of new technologies because it decreases financial insecurity. On the other hand, it may exert a negative effect on adoption decisions because it entails a higher opportunity cost associated with the time required to adopt and manage new technologies (Bellon and Taylor, 1993; Brush *et al.*, 1992). The *Income* variables were included in the estimated models to capture the influence of this factor. These variables group the farmers into three categories: farmers whose family income is totally raised within the farm; farmers whose family income is mainly raised within the farm, but not totally; and, farmers whose family income is mainly raised outside the farm.

The social capital, defined as the degree of social connections of the farmer, as been increasingly recognized as an important determinant in adoption decisions (Mathijs, 2003). In particular, it is expected that more frequent contacts with technicians and consulting agents reduces farmers' uncertainty concerning the new variety thereby increasing the likelihood of adoption. The role of information in adoption decisions has been emphasized by many authors, including Rogers (1962), Kislev and Shchori-Bachrach (1973), Stoneman (1981), Feder and O'Mara (1981), and Feder and Slade (1984). To capture farmers' exposure to information, some authors use the number of times that a farmer received visits of agricultural consultants or technicians, or the number of times that the farmer was present in sessions organized by these professionals. Other authors consider the access to mass media, the literacy rate, education level, or time spent outside the village as appropriate proxies (Feder *et al.*, 1985). In the present analysis, the effect of farmers' social capital on the adoption decision is captured by two variables, one related to professional contacts, and the other related to contacts with other type of agents. The variable *Information* is defined as the number of information sources relevant for the activity of the farmers that they actually used, and intends to capture their degree of information. The variable *Residence*, is a dummy variable taking the value of one if the farmer does not live in the same area of the farm, and zero otherwise.

Characteristics of Farms

The size of the farm is singled out as an important determinant of adoption decisions in many theoretical and empirical studies. It is expected that the larger the farm, the higher the probability and speed of adoption due to the increasing returns to scale characterizing production activities (Heffernan and Green, 1986; Klotz *et al.*, 1995). However, as indicated by Khanna *et al.* (1999), if the activities are characterized by constant returns to scale, the relative advantage of larger farms in their adoption may disappear. In this analysis, the effect of farms' size is introduced in the estimated models through the variable *Agricultural Area*.

Other characteristics expected to influence adoption decisions are crop diversity, and whether the land is owned or rented by the farmer. Nowak (1987), for example, points out that investment in fixed assets is higher for farmers that exploit their own land than for farmers that rent the land. The variable *Percentage Area Owned* is the percentage of the total farm area owned by the farmer, and is intended to capture the effect of landownership on the adoption decision. Dimara and Skuras (1998) argue that crop diversity is used as a strategy to reduce risks, and may, therefore, be taken as a proxy for risk preferences. This factor is included in this analysis through the variable *Percentage Area Dedicated to Apple* (the percentage of the total farm area that is dedicated to apple production), and it is expected that farmers with higher levels of specialization in apple production have higher adoption rates.

Also included as a control variable in the estimated models is the time span between the year of the farmer's first plantation of fruit trees and the year of the survey (*Time Span*). The former corresponds to the date when the farmer first had to consider the possibility of introducing the *Bravo de Esmolfe* variety in the plantation. The data reveals that this date varies to a great extent between the farmers, with some planting as early as 1960, and others in 2004. During this period there were several important technical, social, economic, and political changes that may have affected farmers' decisions to adopt the variety *Bravo de Esmolfe*. In particular, it is expected that farmers who started operation later have more incentives to adopt traditional varieties than farmers who started their activities 20 or 30 years ago, when these varieties were not valued in the market, and the conservation of agrobiodiversity was not on the political and technical agenda. In addition, given the lack of suitable time series data on input and output prices, we follow Burton *et al.* (2003) modeling strategy in including three time-varying dummy variables based on the calendar year to capture epoch effects on the time until adoption. The variable D1974 indicates the period after the Carnation Revolution which changed the Portuguese regime from a dictatorship to a democracy in 1974. The variable D1986 denotes the period after Portugal's accession to the EU in 1986, and the variable D1994 indicates the period over which the PDO designation has been awarded to the *Bravo de Esmolfe* variety (since 1994). The inclusion of these variables is, therefore, a further attempt to control for any systematic changes in the economic conditions faced by farmers which may affect their adoption behavior.

Perceptions and Agricultural Practices

Another factor expected to affect farmers' adoption decisions is their attitudes towards the environment (Burton *et al.*, 2003). It is hypothesized that farmers who use environmentally friendly practices are more likely to adopt the *Bravo de Esmolfe* variety. The variable *Environmental Practices* is a dummy variable taking the value of 1 if farmers' use agricultural practices technically classified as environmentally friendly, and the value of 0 if at least one of those is not used by the farmers. Whether farmers follow more closely the traditional or the sustainable agriculture paradigms as defined by Beus and Dunlap (1990; 1991) is also expected to affect adoption decisions. The variable *Agricultural Paradigm* is an index variable varying between zero and one constructed from the answers given by farmers to a set of 15 questions built to measure their position with respect to these paradigms. This variable takes the value of one when the farmer totally follows the traditional agriculture paradigm, and the value of zero when the farmer totally follows the sustainable agriculture paradigm. Similarly, farmers' perceptions towards different varieties of apple trees may also affect their choices, as shown by Bellon (1996), Brush and Meng (1998) and Negatu and Parikh (1999). Farmers' perceptions of the variety *Bravo de Esmolfe* is included through the index variable *Perceptions Variety* which varies between zero and one. The zero value indicates that the variety *Bravo de Esmolfe* was considered less valuable than the other apple varieties, and the value of one corresponds to the best possible evaluation of this variety compared to others.

A description of the variables appears in Table 1, and Table 2 contains the descriptive statistics of the sample. Variables denoted with the letter t are introduced in the estimated duration models as time-varying covariates; the Education variable is measured at beginning of activity since the highest level of formal education was obtained by these farmers prior to the beginning of activity and did not change over the course of the duration; all other variables are measured at the time of data collection, a subject we return to below.

4. Empirical Results

A. Non-parametric estimates

The non-parametric Kaplan-Meier estimate of the survival function for these data is depicted in Figure 1. The horizontal axis shows the number of years after farmers started the fruit growing activity. The time interval goes from 0 to 41, which corresponds to the longest duration period observed in the sample for a farmer who started his activity in 1960 and only adopted the variety *Bravo de Esmolfe* in the year 2000.[23] The

[23] Year 1960 is the earliest time in our data that we observe farmers' first plantation of fruit trees. This actually corresponds to the year when the Portuguese National Centre for the Study and Promotion of Fruticulture (*Centro Nacional de Estudo e Fomento da Fruticultura*) was created, and farmers' interest in fruitculture first took off (Caldas (1991, 1998)). About 43% of the farmers in the sample first planted fruit trees before 1990. The percentage of farmers planting fruit trees for the first time is highest (13%) in year 1990 which was the year when CAM was recognized as the first Producers Organization in the country under law Reg. CEE 1035/72. This, however, does not correspond to the year we observe more adoptions of the variety *Bravo de Esmolfe*. The earliest year we observe adoptions of this variety in the sample is 1970, and about 36% of all adoptions occurred before 1994 when the variety was awarded the PDO designation. The percentage of all adoptions in the sample is highest (9%) in the years of 1998, 2002, and 2004. These

survival function takes the value of 1 at year 0 since all farmers are considered non-adopters to start with. A sudden drop in the survival function is observed in year 1 because 22.7% of the farmers in the sample adopted this variety during the first year after starting the activity. Subsequently, the annual drop in the survival function is roughly constant, meaning that adoption events occur regularly in time, but become substantially less frequent after the 28th year subsequent to the beginning of the fruit growing activity. Figure 1 also shows that approximately 50% of the farmers adopted the variety *Bravo de Esmolfe* in the first 15 years after starting the activity. More precisely, the Kaplan-Meier estimate of the median duration is between 17 and 18 years.

B. Semi--parametric and parametric estimates

The results of the estimated duration models are displayed in Table 3. The dependent variable in these models (Cox, Exponential and Weibull) is the length of time until adoption of the *Bravo de Esmolfe* variety, or, if adoption did not occur, it is the length of time that goes between the first plantation of fruit trees by the farmer and the date of the interview. The latter cases correspond to censored data on the right, since all that is known is the time origin of the duration but not its end. Thus, the dependent variable controls both the occurrence and the timing of adoptions.

Before turning to a discussion of Table 3, it should be pointed out that Wald tests were conducted to test for parameter restrictions in each of the estimated models. The test statistic is chi-square distributed with *k* degrees of freedom, where *k* is the number of restrictions. The results of this test for each of the estimated models are shown at the bottom of Table 3, and in each case indicate that the null hypothesis that all the slope coefficients are equal to zero be rejected at less than the 0.01 significance level.

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features of the data accord with the estimates produced by the Portuguese National Statistical Institute (*Instituto National de Estatística*) indicating that the area dedicated to the plantation of this variety increased 55% between the years 1998 and 2002 while the area dedicated to the plantation of apple trees in general decreased about 16% within the same period of time (INE (1998, 2002)).

In addition, likelihood ratio tests were conducted to verify whether the coefficients of the statistically insignificant variables are jointly zero in each of the estimated duration models. The test statistic is defined as $-2(L_R-L_{UR})$, where L_R and L_{UR} are the values of the log-likelihood functions for the restricted and unrestricted models. The computed test statistics are $\chi^2_{(13)}=81.2$, $\chi^2_{(14)}=64.9$, and $\chi^2_{(14)}=62.7$ for the Cox, Exponential, and Weibull models respectively. We therefore do not find evidence justifying the omission of the statistically insignificant variables included in these models. Because we have no prior expectations concerning the nature of the baseline hazard, the results of the semi-parametric Cox's model are of utmost importance to us. We therefore conducted a further test to check for misspecification in this model. A remarkably powerful test in this context is the link test suggested by Pregibon (1980), and documented in StataCorp (2005). The result of this test reveals no problem with our specification of the Cox's model.[24]

Remaining agnostic as to the functional form of the baseline hazard, Table 3 first presents the maximum likelihood estimates of Cox's proportional hazard model. For ease of interpretation, the results are displayed in terms of hazard ratios: these can take values inferior, equal or superior to 1, meaning that the associated explanatory variable has a negative, null, or positive effect on the hazard adoption rate, respectively. Inspection of the results for Cox's model reveals that farmers' age, experience and education level have no effect on the hazard adoption rate since the estimated hazard ratios associated with these variables take values close to 1, and are not statistically significant at conventional significance levels. Although lacking statistical significance, the included income variables

[24] The link test we applied is based on the idea that one should not find any additional significant explanatory variables in our model if it is to be judged as properly specified. Let $y=f(X\beta)$ be the initially specified model, and $\hat{\beta}$ the vector of parameter estimates. The link test computes two additional variables $Z=X\hat{\beta}$ and $Z^2=(X\hat{\beta})^2$, and refits the model with these two variables. If the initial model is correctly specified, the coefficient of the variable Z^2 is not statistically different from zero. In our application, the coefficient estimate of this variable equals -0.203 with a p-value=0.323. We, therefore, do not reject the hypothesis that the model is correctly specified,

show a substantial impact on the hazard adoption in terms of magnitude, constituting *weak* evidence in favour of the argument that the opportunity to earn income outside of the farm facilitates the adoption of new varieties by reducing financial insecurity.

Importantly, the variable *Information* exerts a positive and statistically significant effect on the conditional probability of adoption. Its effect is also quite substantial in terms of magnitude: ceteris paribus, the use of one more information source relevant to the farmers' activity is associated with a 22 percent higher hazard rate, i.e, shorter adoption time. The variable *Residence* impacts negatively the hazard rate, but its effect is not statistically significant at conventional significance levels.

With respect to the impact of farms' characteristics, we observe that two out of the four included time-invariant variables have a significant effect on the hazard adoption rate. The variable measuring the total agricultural area of the farm was included in the model in its natural logarithm form because an analysis of the martingale residuals revealed specification problems with this covariate in its original form.[25] As expected, ceteris paribus, the higher the agricultural area of the farm, the higher is the conditional risk of adoption of the variety *Bravo de Esmolfe*. Similarly, controlling for the other variables, the estimated hazard of adoption is about 2 percent higher for each percentage point increase in the total agricultural area dedicated to growing apple trees. A reasonable deduction from this finding is that farmers with higher levels of specialization in growing specific fruit trees have higher adoption rates of their traditional varieties. While we expected the Percentage Area Owned by the farmer and Time Span to be, respectively, positively and negatively related to the hazard adoption rate, this does not appear to be the case as the hazard ratios associated to these variables are near unity, and statistically

[25] Martingale residuals may be defined as the difference over time of the observed number of adoptions minus the number of adoptions predicted by the model. If an adequate functional form of a covariate has been used in the model, then a plot of the martingale residuals versus the covariate should produce a smooth curve close to linear. In our application, the fitted curve against the variable Agricultural Area was far from linear, so that a transformation of this covariate was necessary to provide a better fit. A discussion of martingale residuals and its usefulness in assessing the adequacy of the functional forms of individual covariates may be found in Fleming and Harrington (1991).

insignificant. Of the included epoch dummies, only D1994 is statistically significant, indicating that time until adoption is substantially decreased after the attribution of the PDO designation the *Bravo de Esmolfe* variety.

Although lacking statistical significance, the variables intended to capture farmers' perceptions and agricultural practices reveal a substantial impact on the adoption hazard in terms of magnitude. According to our analysis, the estimated hazard of adoption among farmers who use environmentally friendly practices is about 1.5 times that of those who do not use such practices. Similarly, the estimated adoption hazards are clearly substantially increased the closer farmers follow the traditional agricultural paradigm, and the more valuable they judge this apple variety comparatively to other apple varieties.

To further check the robustness of these results, we also estimated the exponential and the Weibull proportional hazards models.[26] As previously noted, estimation of these models produces more efficient estimates of the covariates' coefficients if the baseline hazard is correctly specified. The results displayed in Table 3 reveal that the estimates in these models differ little from the Cox estimates both in size and statistical significance. The closeness of the Cox and the exponential/Weibull estimates suggests that any bias arising from unobserved heterogeneity (or misspecified baseline hazard) is not large in this sample.

As in any regression analysis, failure to account for unobserved heterogeneity (ie, variability between individuals due to unmeasured characteristics) leads to biased

[26] From a purely statistical view, the Akaike information criterion (AIC) is often used to select the best parametric survival model. This measure is defined as AIC=-2lnL+2(k+c), where lnL is the log likelihood, *k* is the number of model regressors, and *c* the number of model-specific distributional parameters (Cleves *et al.* (2004, p. 249). The log likelihood is -70.605459 and -70.560809 for the estimated exponential and Weibull models, respectively. The number of covariates is 17 in both models, and *c* equals 1 and 2 in the exponential and Weibull models, respectively. The AIC is 177.2109 in the exponential model, and 179.1216 in the Weibull. Per the AIC criterion, therefore, the exponential model is to be selected. In addition, a Wald test for the null hypothesis that the parameter *a* in the Weibull model equals unity yields the test statistic 0.37 (p-value=0.71) and, therefore, we cannot reject the hypothesis that the hazard is a constant (the obtained estimate for the parameter *a* is 1.06 with an estimated standard error of 0.170).

parameter estimates if unmeasured variables are correlated with the covariates included in the model. While comparison of estimates obtained through different models is useful in assessing the potential presence of unobserved heterogeneity, it is worth proceeding with formal testing for unobserved heterogeneity in the models. The usual approach to test for unobserved heterogeneity is to estimate the models including a random effect, also known as frailty, which represents unobserved risk factors that are specific to an individual. The usual distribution functions chosen for the random effects are the gamma and the inverse-Gaussian distributions, although any continuous distribution with mean unity and finite variance may be chosen. The testing procedure for unobserved heterogeneity consists in applying a likelihood-ratio test to the null hypothesis that the frailty variance component is zero (Hougaard, 1986). In our analysis, the estimates for the frailty variance are near zero using both the gamma and the inverse-Gaussian distributions, and in each case the likelihood-ratio test failed to reject the null hypothesis with *p*-values equal to one. Thus, this formal statistical testing corroborates the conclusion that no significant heterogeneity is present in our sample.

An important observation worth adding here, however, is that, as noted earlier, many of the covariates are measured at the time of data collection and treated as time-invariant when in fact they are time-varying in nature. While this treatment is probably valid for some covariates, such as geographical location, it is possible that other farm and farmer characteristics, including perceptions and agricultural practices, evolve over time. Thus, without relying on recall data, it is not possible to determine whether responses expressed at the time of data collection were held at the time of adoption, potentially influencing the adoption decision, or whether they have changed after adoption itself and are, consequently, immaterial to the adoption decision. Although a complete examination of this empirical question would require a log-term longitudinal survey of farmers, we investigate the potential extent of this problem in the present sample comparing the responses of recent adopters with those who adopted a long time ago concerning all the time-invariant variables measured at the time of data collection. More precisely, we divided the sample of adopters in four groups: those who adopted prior to 1989; those who adopted between the years of 1990 and 1995; those who adopted between the years of 1996 and 1999; and those who adopted between the years of 2000 and 2004. We would expect to find significant differences in the responses given by the adopters in these different groups, particularly between those belonging to the first and last groups, if the event of adoption is altering the values of the variables Income and Information, and of those under the headings Farm Characteristics, and Perceptions and Agricultural Practices. The results, however, reveal no statistically significant differences in the values of the variables amongst the groups using appropriate (concerning the variables' scale) nonparametric Chi-square and Kruskal-Wallis tests (results available from the authors). This suggests that, while caution is certainly required in interpreting the results in studies of this type using ex post data, any risk of endogeneity is not large in this sample as adoption itself does not seem to be altering the values of the covariates which were likely formed prior to adoption.

Also reported in Table 3 for purpose of comparison are binomial probit estimates. The time-variant covariates Age and Experience are introduced in this model as time-invariant taking their values at the time of data collection, and the time-variant epoch dummies take the unit value if farmers' first plantation of fruit trees occurred in the indicated calendar years. To aid in interpretation, the results are displayed in terms of marginal effects showing the impact of each variable on the probability of adoption.[27] Because the variable Residence predicts the dependent variable perfectly, it was dropped from this estimation procedure. Comparison of the Cox and probit results reveals that, in

[27] The marginal effects are calculated at the mean values of the continuous variables. For the dummy variables the effect of a change from 0 to 1 is calculated by computing the change in the probability of adoption evaluated at the mean index function for the other regressors. The estimated probit model predicts 90% of the observations correctly.

general, the *direction* of the effects of the covariates on the probability of adoption is the same as on the hazard of adoption, and accords to theoretical expectations. The exceptions to this observation are the effects of the included Income variables, Information and epoch dummies. Contrary to their effects on the adoption hazard, the income variables impact negatively the probability of adoption of the *Bravo de Esmolfe* variety, a finding that supports the argument that the opportunity to earn income outside of the farm hinders adoption decisions because it entails higher opportunity costs associated with the adoption of new products or processes. Likewise, contrary to the Cox's results, and contrary to *a priori* expectations, the most recent epoch dummies exert a negative effect on the probability of adoption, indicating that farmers who installed their first plantation of fruit trees more recently are less likely to adopt traditional varieties.

An important difference between the Cox and the probit results concerns the statistical significance of the explanatory variables included in this analysis. While only four of the included variables show a statistically significant effect on the hazard of adoption, we observe from the probit results that only four of the covariates (Information, Percentage Area Owned, TimeSpan and D1974) do not impact the probability of adoption at conventional significance levels. These findings are in line with those of Burton *et al.* (2003) who also found many significant predictors of adoption in static models to be insignificant in their duration analysis. To the extent that the dependent variable in the Cox model controls both the occurrence and the timing of adoptions, but the probit model only controls for the occurrence of adoptions, these results might be interpreted as an indication that the factors that explain adoption decisions are not necessarily those that explain such decisions once the time of adoption occurrence is taken into account. Accordingly, the results suggest that the included variables capturing the characteristics of the farms, the individual characteristics of the farmers, as well as their attitudes and perceptions, are, in general, powerful determinants of the decision to adopt regional varieties of fruit trees, but their significance is diminished when explaining the time that farmers take to actually adopt such varieties. In light of this interpretation, the results also indicate that the size of the agricultural area of the farm, and the percentage of that area dedicated to trees are powerful determinants of both the decision to adopt and of the time taken for adoption, while the variable Information is a significant predictor of the adoption rate per unit time but has no significant impact on the unconditional probability of adoption. An important observation here, however, is that considerable caution needs to be exercised when formulating these inferences because the probit estimates may be misleading due to the probit's failure to account for temporal dependence in the data. In fact, the results from the comparison herein along with the findings reported by Burton *et al.* (2003) suggest that considerable caution is required in interpreting the results from the static bivariate analyses of adoption data reported in the literature. As noted, while not claiming that these studies draw incorrect conclusions, the validity of their substantive findings might be questioned, a subject that would benefit from further research comparing the findings from static and dynamic modeling techniques of adoption data in agriculture.

5. Conclusion and Discussion

Whether one believes that the market will create suitable incentives for agrobiodiversity conservation or one advocates active international and national policy to address the problem of agrobiodiversity loss, the effectiveness of either may depend on whether farmers' decisions to adopt *in situ* and on-farm conservation measures are influenced by their perceptions and attitudes towards the environment, their human and social capital, farm characteristics, and other economic or noneconomic factors affected by strategies. Since neither farms nor farmers are all alike, we may expect that there will be differences in whether a particular agrobiodiversity measure is adopted and when. Currently, the worldwide concern over climate change and biodiversity loss highlights the importance of agrobiodiversity conservation. If agrobiodiversity loss is to be slowed down, or even reversed, policy-makers need an understanding of the factors that influence farmers' adoption of agrobiodiversity measures. Given that many agrobiodiversity problems are inherently site-specific, such an understanding is enhanced by collecting data at a geographically relevant scale.

Accordingly, the objective of this paper has been to examine the impact of farmers' characteristics, their perceptions and agricultural practices, and farm characteristics on farmer's adoption of traditional varieties of fruit trees. The study focused on a particular apple variety originated in the interior central region of Portugal, known as *Bravo de Esmolfe*, which is considered an important resource-conserving measure. In line with previous empirical studies looking at the adoption of agricultural technologies using standard logit/probit econometric techniques, we found that a number of individual factors influence adoption behaviour. According to our probit results, traditional varieties of fruit trees are more frequently adopted by younger and more educated farmers, and by those whose perceptions and agricultural practices are in general more environmentally friendly. Moreover, farmers with larger agricultural areas and more specialized in apple production are more likely to adopt traditional varieties of apple trees. Conversely, these results suggest that farmers engaged in off-farm employment are less likely to adopt these varieties.

However, as previously noted, standard logit/probit techniques do not take into account the time-dependent nature of adoption data and may give rise to misleading results. In fact, while generally conforming to theoretical expectations and previous empirical findings both in sign and magnitude, the statistical significance of many of these factors drops once more appropriate econometric techniques are applied to the analysis of the same data. We analysed the data using duration methods that not only directly address the censoring and temporal-dependency problems, but also allows us to control for both the occurrence and the timing of adoptions. The results show that the size of the farms' agricultural area, and farmers' specialization in apple production are significant predictors of the hazard adoption rate. Importantly, and contrary to the probit results, the variable *Information* exerts a statistically significant impact on the hazard adoption rate. The statistical significance of this variable is borne out in each of the duration methods we applied to the data – semiparametric, and parametric. It is, therefore, a robust result with an important policy implication.

In particular, our findings based on semi-parametric and parametric duration analyses suggest that, all else the same, the use of one more information source relevant to the farmers' activity is associated with a 22 to 32 percent higher hazard rate of adoption. This constitutes strong evidence that good extension services providing farmers with abundant information covering both technical and broader issues are fundamental components to effect the adoption of resource-conserving measures. Importantly, these findings indicate that farmers' weak response to previous agri-environmental measures aiming at the protection of regional varieties of fruit trees in Portugal may have been due to the lack of information dissemination concerning the advantages of growing such varieties. In the face of our results, it is predictable that once farmers are aware of such advantages, they implement the necessary changes and respond positively to agrobiodiversity conservation measures. It is therefore important that governments and other relevant institutions provide reliable and accessible information, as well as technical guidance adapted to local conditions in order to foster a successful adoption process of agrobiodiversity conservation measures.

Like in every empirical study, several limitations associated with this one require prudence. First, the results rest on the analysis of a relatively small sample of fruit growers located in a specific geographical area, and focus only on a particular variety of fruit trees. Although it may be argued that intensive sampling of site and resource-specific agricultural practices and adoption processes are more informative for the design of effective policy measures than broad surveys designed to capture international or national averages that are subject to potential aggregation biases, it should still be borne in mind that the findings from these focused studies may not transfer easily to other settings. Second, the data collected does not track changes on the values of many of the covariates over time, precluding us from exploring how the timing of the adoptions relates to changes in the values of those covariates. Similarly, the lack of data on costs and prices, and their evolution over time, constitutes an important limitation of the analysis. Finally, the data was collected retrospectively, with farmers asked to recall the dates of the beginning of their activity, and the date they adopted the particular variety under analysis, which, given the length of the recall period, may entail a significant recall error.

Despite these caveats, this study has succeeded in developing and implementing a field survey that has contributed to an understanding of how farmers choose their production practices. In particular, our extensive econometric analysis allowed us to identify an important policy variable affecting the adoption of resource-conserving measures, providing a valuable insight into the mechanisms that policy-makers need to implement in order to help the process of adoption of agrobiodiversity conservation measures.

References

Adesina, A. A., and Baidu-Forson, J. (1995), "Farmers' perceptions and adoption of new agricultural technology: evidence from analysis in Burkina Faso and Guinea, West Africa", *Agricultural Economics*, 13, 1-9.

Altieri, M., and Merrick, L. (1987), "In situ conservation of crop genetic resources through maintenance of traditional farming systems", *Economic Botany*. 41, 86-96.

Bartoloni, E., and Baussola, M. (2001); "The Determinants of Technology Adoption in Italian Manufacturing Industries", *Review of Industrial Organization*, 19(3), 305-328.

Beck, N.; Katz, J.N.; and Tucker, R. (1998), "Taking Time Seriously: Time-Series-Cross-Section Analysis with a Binary Dependent Variable", *American Journal of Political Science*, 42(4), 1260-1288.

Bellon, M. (1996), "The dynamics of crop infraspecific diversity: a conceptual framework at the farmer level", *Economic Botany*, 50, 26-39.

Bellon, M., and Taylor, J. (1993), "Folk soil taxonomy and the partial adoption of new seed varieties", *Economic Development and Cultural Change*, 41, 763-786.

Bergström, R., and Edin, P.A. (1992), "Time Aggregation and the Distributional Shape of Unemployment Duration", *Journal of Applied Economics*, 7(1), 5-30.

Beus, E., and Dunlap, R. (1990), "Conventional versus alternative agriculture: the paradigmatic roots of the debate", *Rural Sociology*, 55(4), 590-616.

Beus, E., and Dunlap, R. (1991), "Measuring adherence to alternative vs. conventional agricultural paradigms: a proposed scale", *Rural Sociology*, 56 (3), 432-460.

Brennan, J.; Godden, D.; Smale, M.; and Meng, E. (1999), "Breeder demand for and utilisation of wheat genetic resources in Australia", *Plant Varieties and Seeds*, 12, 113-127.

Brush, S.; Taylor, J.; and Bellon, M. (1992), "Technology adoption and biological diversity in Andean potato agriculture", *Journal of Development Economics*, 39, 365-387.

Brush, S., and Meng, E. (1998), "Farmer's valuation and conservation of crop genetic resources", *Genetic Resources and Crop Evolution*, 45, 139-150.

Burton, M.; Rigby, D.; and Young, T. (2003), "Modelling the adoption of organic horticultural technology in the UK using Duration Analysis", *Australian Journal of Agricultural and Resource Economics*, 47(1), 29-54.

Caffey, R., and Kazmierczak, R. (1994), "Factors Influencing Technology Adoption in a Louisiana Aquaculture System, *Journal of Agricultural and Applied Economics*, 26(1), 264-274.

Caldas, E.C. (1991), *A Agricultura Portuguesa Através dos Tempos*, Lisboa: Instituto Nacional de Investigação Científica.

Caldas, E.C. (1998), *A Agricultura na História de Portugal*, Lisboa: Empresa de Publicações Nacionais (E.P.N.).

Carey J. M., and Zilberman, D. (2002), "A Model of Investment under Uncertainty: Modern Irrigation Technology and Emerging Markets in Water," *American Journal of Agricultural Economics*, 84, 171-83.

Cleves, M. A.; Gould, W. W.; and Gutierrez, R. G. (2004), *An Introduction to Survival Analysis using Stata*, Texas, USA: Stata Press.

Collet, D. (1994), *Modelling Survival Data in Medical Research*, London: Chapman & Hall.
Comer, S.; Ekanem, E.; Muhammed, S.; Singh, S.; and Teguegue, F. (1999), "Sustainable and conventional farmers: a comparison of socio-economic characteristics, attitudes and beliefs", *Journal of Sustainable Agriculture*, 15(1), 29-45.

Cox, D., and Snell, E. (1968), "A general definition of residuals", *Journal of the Royal Statistical Society*, B, 30, 248-275.

Cox, D. (1972), "Regression models and life-tables", *Journal of the Royal Statistical Society*, B, 30, 187-220.

Dimara, E.; Skuras, D. (1998), "Adoption of New Tobacco Varieties in Greece: Impacts of Empirical Findings on Policy Design, *Agricultural Economics*, 19(3), 297-307.

Dixit, A.K., and Pindyck, R.S. (1994), *Investment under Uncertainty,* Princeton University Press.

Epperson, J.; Pachico, D.; and Guevara, C. (1997), "A cost analysis of maintaining cassava plant genetic resources", *Crop Science*, 37, 1641-1649.

European Environment Agency (2007), *Europe's Environment: The Fourth Assessment*, EEA, Copenhagen, Denmark.

Faria, A.; Fenn, P.; and Bruce, A. (2002), "Determinants of Adoption of Flexible Production Technologies: Evidence from Portuguese Manufacturing Industry, *Economics of Innovation and New Technology*, 11(6), 569-80.

Feder, G., and O'Mara, G. (1981), "Farm size and the adoption of green revolution technology", *Economic Development and Cultural Change*, 30, 59-76.

Feder, G., and O'Mara, G. (1982), "On information and innovation diffusion: a Bayesian approach", *American Journal of Agricultural Economics*, 64, 145-147.

Feder, G., and Slade, R. (1984), "The acquisition of information and the adoption of new technology", *American Journal of Agricultural Economics*, 66, 312-320.

Feder, G.; Just, R.; and Zilberman, D. (1985), "Adoption of agricultural innovations in developing countries: a survey", *Economic Development and Cultural Change*, 33, 255-298.

Fleming, T. R., and Harrington, D. P. (1991), *Counting Processes and Survival Analysis*, New York: John Wiley & Sons.

Foltz, J., and Chang, H. (2002), "The Adoption and Profitability of rbST on Connecticut Dairy Farms, *American Journal of Agricultural Economics*, 84(4), 1021-1032.

Fuglie, K., and Kascak, C. (2001), "Adoption and diffusion of natural-resource-conserving agricultural technology", *Review of Agricultural Economics*, 23(2), 386-403.

Gasson, R. (1988), "Farm diversification and rural development", *Journal of Agricultural Economics*, 39, 175-182.

Grambsch, P. M., and Therneau, T. M. (1994), "Proportional hazard tests and diagnostics based on weighted residuals", *Biometrika*, 81, 515-526.

Hannan, T., and McDowell, J. (1987), "Rival precedence and dynamics of technology adoption: an empirical analysis", *Economica*, 54, 155-171.

Hiebert, D. (1974), "Risk, Learning, and the Adoption of Fertilizer-Responsive Seed Varieties", *American Journal of Agricultural Economics*, 56, 764-768.

Heffernan, W., and Green, G. (1986), "Farm size and soil loss: prospects for a sustainable agriculture", *Rural Sociology*, 51, 31-42.

Heisey, P.; Smale, M; Byerlee, D.; and Souza, E. (1997), "Wheat rusts and the costs of genetic diversity in the Punjab of Pakistan", *American Journal of Agricultural Economics*, 79, 726-737.

Hooks, G.; Napier, T.; and Carter, M. (1983), "Correlates of adoption behaviour: the case of farm technologies", *Rural Sociology*, 48(2), 308-323.

Hougaard, P. (1986), "Survival models for heterogeneous populations derived from stable distributions", *Biometrika*, 73, 387-396.

Hougaard, P. (2000), *Analysis of Multivariate Survival Data*, New York: Springer-Verlag.

INE (1998), *Inquéritos Base às Plantações de Árvores de Fruto*, available at http://www.ine.pt.

INE (2002), *Inquéritos Base às Plantações de Árvores de Fruto*, available at http://www.ine.pt.

IUCN (2007), *2007 IUCN Red List of Threatened Species*. <http://www.iucnredlist.org>.

Kaplan, E. L., and Meier, P. (1958), "Nonparametric estimation from incomplete observations", *Journal of the American Statistical Association*, 53, 457-481.

Karshenas, M., and Stoneman, P. (1993), "Rank, stock, order and epidemic effects in the diffusion of new process technologies: an empirical model", *Rand Journal of Economics*, 24, 503-528.

Khanna, M.; Epouhe, O.; and Hornbaker, R. (1999), "Site-specific crop management: adoption patterns and incentives", *Review of Agricultural Economics*, 21(2), 455-472.

Kislev, Y., and Shchori-Bachrach, R. (1973), "The process of an innovation cycle", *American Journal of Agricultural Economics*, 55, 28-37.

Klein, J. P., and Moeschberger, M. L. (1997), *Survival Analysis: Techniques for Censored and Truncated Data*, New York: Springer-Verlag.

Klotz, C.; Saha, A.; and Butler, L. (1995), "The Role of Information in Technology Adoption: The Case of rbST in the California Dairy Industry", *Review of Agricultural Economics*, 17(3), 287-98.

Lancaster, T. (1972), "A stochastic model for the duration of a strike", *Journal of the Royal Statistic Society*, 135, 257-271.

Lancaster, T. (1990), *The Econometric Analysis of Transition Data*, Cambridge: Cambridge University Press.

Levin, S., and Meisel, J. (1987), "A dynamic analysis of the adoption of a new technology: the case of optical scanners", *Review of Economics and Statistics*, 69(1), 12-17.

Lindner, R.K., Fischer, A.J., and Pardey, P.G. (1979), "The time to adoption", *Economics Letters*, 2(2), 187-190.

Mathijs, E. (2003), "Social capital and farmers' willingness to adopt country side stewardship schemes", *Outlook on Agriculture*, 32(1), 13-16.

Negatu, W., and Parikh, A. (1999), "The Impact of Perception and Other Factors on the Adoption of Agricultural Technology in the Moret and Jiru Woreda (District) of Ethiopia", *Agricultural Economics*, 21(2), 205-216.

Nowak, P.J. (1987), "The adoption of agricultural conservation technologies: economic and diffusion explanations", *Rural Sociology*, 52, 208-220.

Pregibon, D. (1980), "Goodness of link tests for generalized linear models", *Applied Statistics*, 29, 15-24.

Rahm, M.R., and Huffman, W.E. (1984), "The adoption of reduced tillage: the role of human capital and others variables", *American Journal of Agricultural Economics*, November: 405-413.

Rogers, E. (1962), *Diffusion of Innovations*, New York: Free Press of Glencoe.

Shucksmith, M., and Smith, R. (1991), "Farm household strategies and pluriactivity in Upland Scotland", *Journal of Agricultural Economics*, 42, 340-353.

Smale, M., and Bellon, M.R. (1999), "A conceptual framework for valuing on-farm genetic resources", in Wood, D. and Lenné, J.M. (eds.), *Biodiversity: Characterization, Utilization, and Management*, CAB International, 387-408.

Somda, J.; Nianogo, J.; Nassa, S.; and Sanou, S. (2002), "Soil Fertility Management and Socio-economic Factors in Crop-Livestock Systems in Burkina Faso: A Case Study of Composting Technology", *Ecological Economics*, 43(2-3), 175-83.

StataCorp (2005), Stata Base Reference Manual, Release 9, College Station, TX: Stata Press.

Stoneman, P. (1981), "Intra firm diffusion, Bayesian learning and Profitability", *Economic Journal*, 91, 375-388.

Stoneman, P. L., and David P. A. (1986), "Adoption Subsidies vs Information Provision as Instruments of Technology Policy", *The Economic Journal*, 96, 142-150.

Therneau, T., and Grambsch, P. (2000), *Modeling Survival Data: Extending the Cox Model*, New York: Springer-Verlag.

Table 1 – Description of Variables

Variable	Description
Characteristics of Farmers	
Age (t)	Age, in years
Experience (t)	Experience in agricultural activities, in years
Education	Number of years of schooling at beginning of activity
Income100	Dummy variable equal to 1 if income from farm is 100% of total family income, 0 otherwise
Income<100	Dummy variable equal to 1 if income from farm is higher than or equal to 50% and lower than 100% of total family income, 0 otherwise
Income<50	Dummy variable equal to 1 if income from farm is less than 50% of total family income, 0 otherwise
Information	Number of information sources relevant for the farming activity actually used
Residence	Dummy variable equal to 1 if the farm is not in the same district as the farmer's residence, 0 otherwise
Characteristics of Farms	
Agricultural Area	Total agricultural area of the farm, in hectares
Percentage Area Owned	Percentage of the total farm area owned by the farmer
Percentage Area Dedicated Apple	Percentage of total agricultural area dedicated to apple trees
Time Span	Time span between the year of the farmer's first plantation of fruit trees and the year of the survey, in years
D1974 (t)	Dummy variable equal to 1 if calendar year is 1974 and after, 0 otherwise
D1986 (t)	Dummy variable equal to 1 if calendar year is 1986 and after, 0 otherwise
D1994 (t)	Dummy variable equal to 1 if calendar year is 1994 and after, 0 otherwise
Perceptions and Agricultural Practices	
Environmental Practices	Dummy variable equal to 1 if farmer uses agricultural practices technically classified as environmentally friendly, 0 otherwise
Agricultural Paradigm	Index of farmer's attitudes towards the agricultural paradigm; varies between 0 (sustainable) and 1(traditional)
Perceptions Variety	Index of farmer's perceptions towards the variety *Bravo de Esmolfe*; varies between 0 (lowest evaluation) and 1(best evaluation)

Table 2 – Means and Standard Deviations

Variable	Full Sample	Adopters	Non-Adopters
Characteristics of Farmers			
Age	42.89	40.82	45.84
	(11.72)	(11.58)	(11.45)
Experience	12.73	12.50	13.06
	(12.31)	(12.04)	(12.87)
Education	7.71	8.68	6.32
	(4.85)	(4.84)	(4.58)
Income100	0.15	0.20	0.06
Income<100	0.24	0.23	0.26
Income<50	0.61	0.57	0.68
Information	2.51	2.84	2.03
	(1.49)	(1.79)	(0.71)
Residence	0.08	0.14	0.00
Characteristics of Farms			
Agricultural Area	10.31	14.14	4.89
	(19.23)	(24.32)	(3.59)
Percentage Area Owned	88.90	83.86	96.05
	(27.67)	(32.03)	(18.10)
Percentage Area Dedicated Apple	50.18	56.11	41.77
	(34.06)	(36.52)	(28.71)
Time Span	17.77	18.57	16.64
	(8.92)	(9.77)	(7.57)
D1974	0.87	0.82	0.93
D1986	0.69	0.64	0.77
D1994	0.17	0.20	0.13
Perceptions and Agricultural Practices			
Environmental Practices	0.26	0.40	0.07
Agricultural Paradigm	0.73	0.73	0.73
	(0.09)	(0.09)	(0.09)
Perceptions Variety	0.55	0.56	0.54
	(0.10)	(0.10)	(0.11)
Sample size	75	44	31

Figure 1 – Kaplan-Meier estimate of the survival function

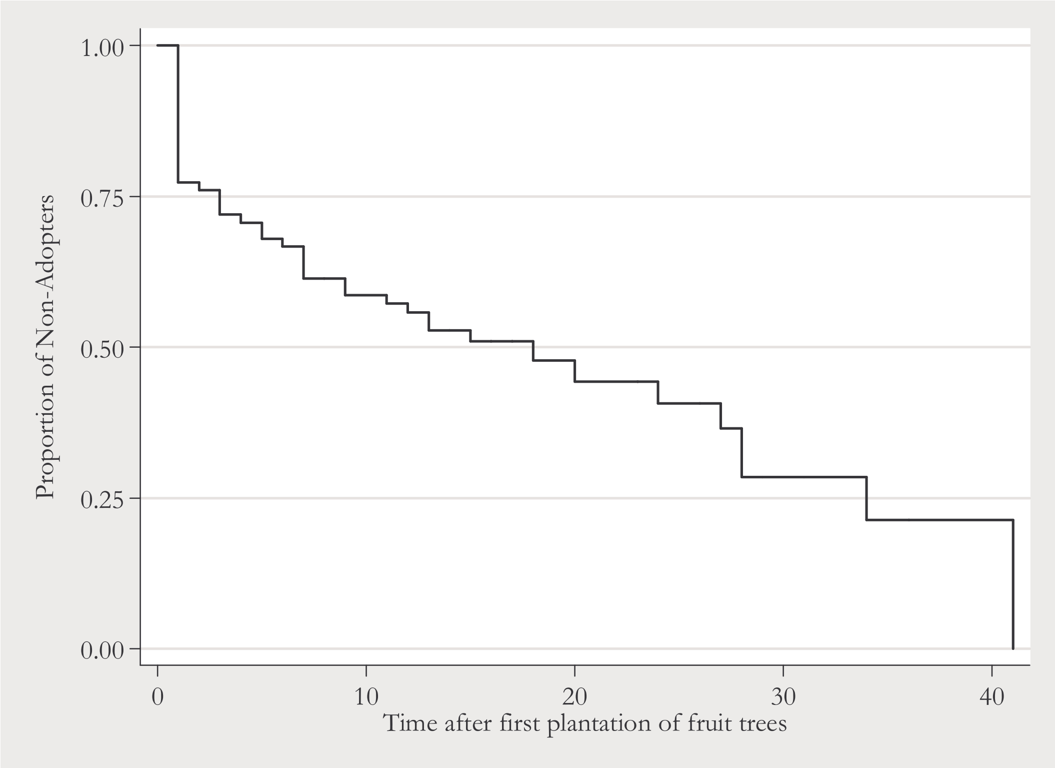

Table 3 – Estimated Duration Models

Variable	Cox		Exponential		Weibull		Probit	
	HR	SE	HR	SE	HR	SE	ME	SE
Characteristics of Farmers								
Age(t)	0.997	(0.003)	0.960	(0.024)	0.958	(0.027)	-0.038‡	(0.017)
Experience(t)	1.002	(0.002)	1.018	(0.025)	1.018	(0.026)	0.084‡	(0.033)
Education	1.035	(0.048)	1.030	(0.052)	1.030	(0.053)	0.128‡	(0.063)
Income<100	1.212	(0.688)	1.533	(0.943)	1.542	(0.955)	-0.999*	(0.001)
Income<50	1.032	(0.452)	1.504	(0.847)	1.502	(0.852)	-0.917*	(0.146)
Information	1.222‡	(0.101)	1.307‡	(0.166)	1.318‡	(0.173)	-0.054	(0.108)
Residence	0.889	(0.591)	1.020	(1.006)	1.045	(1.087)	_	_
Characteristics of Farms								
lnAgricultural Area	1.977*	(0.478)	2.016‡	(0.574)	2.008‡	(0.584)	1.190‡	(0.485)
Percentage Area Owned	0.999	(0.005)	0.999	(0.007)	0.999	(0.007)	-0.002	(0.003)
Percentage Area Dedicated Apple	1.022*	(0.006)	1.027*	(0.007)	1.028*	(0.007)	0.040‡	(0.017)
Time Span	1.012	(0.035)	0.991	(0.032)	0.986	(0.035)	0.029	(0.029)
D1974(t)	0.612	(0.329)	0.242	(0.308)	0.224	(0.291)	0.233	(0.873)
D1986(t)	1.999	(1.085)	2.386	(2.816)	2.315	(2.788)	-0.423‡	(0.198)
D1994(t)	1.257†	(0.149)	1.952	(0.993)	1.833	(0.961)	-0.911*	(0.210)
Perceptions and Agricultural Practices								
Environmental Practices	1.527	(0.564)	1.637	(0.801)	1.649	(0.820)	0.525*	(0.150)
Agricultural Paradigm	1.181	(2.019)	1.833	(3.569)	1.861	(3.694)	4.330*	(1.573)
Perceptions Variety	2.911	(5.606)	3.599	(7.418)	3.454	(7.344)	5.686‡	(2.433)
	Wald $\chi^2_{(17)}$=99.57*		Wald $\chi^2_{(14)}$=148.57*		Wald $\chi^2_{(14)}$=77.54*		Wald $\chi^2_{(16)}$=43.23*	

Note: HR stands for Hazard Ratio, and ME for marginal effects. Robust standard errors (SE) are in parentheses. *Statistically significant at p-value<0.01; ‡Statistically significant at p-value<0.05; †Statistically significant at p-value<0.1