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REVEALED PREFERENCE LAND USE MODELS IN ANDALUSIA: INTEGRATING COMMERCIAL AND ENVIRONMENTAL VARIABLES

JOSE L. OVIEDO
&
ALEJANDRO CAPARRÓS

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

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INSTITUTO DE POLÍTICAS Y BIENES PÚBLICOS

INSTITUTO DE POLÍTICAS Y BIENES PÚBLICOS – CSIC

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Instituto de Políticas y Bienes Públicos (CSIC-IPP)
Consejo Superior de Investigaciones Científicas
C/ Albasanz, 26-28
28037 Madrid (España)

Tel: +34 91 6022300
Fax: +34 91 3045710

http://www.ipp.csic.es

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Revealed preference land use models in Andalusia: integrating commercial and environmental variables

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Jose L. Oviedo (*corresponding author*)
Associate Research Professor, Institute of Public Goods and Polices (IPP)
Consejo Superior de Investigaciones Científicas (CSIC)
Albasanz 26-28, 28037 Madrid, Spain. E-mail: jose.oviedo@csic.es

Alejandro Caparrós
Associate Research Professor, Institute of Public Goods and Polices (IPP)
Consejo Superior de Investigaciones Científicas (CSIC)
Albasanz 26-28, 28037 Madrid, Spain. E-mail: alejandro.caparros@csic.es

Abstract

We investigate transitions among crop, grass and forest land uses in Andalusia (Spain) through an econometric model that uses individual land use decisions observed in the Corine Land Cover database as dependent variable, and net income, subsidies and biophysical and environmental factors as explanatory variables. Using multinomial logit models (fixed and random parameters), we identify both monetary and environmental and biophysical variables as significant in explaining land use decisions, but model performance significantly improves with the latter variables. We also identify the role of inertia but its effect is low as compared to the other variables. Based on the estimated model, we simulate the hypothetical variation of some explanatory variables in four scenarios up to 2022 and 2038. We find no large changes in land uses in most of the scenarios except for the one with an important reduction of subsidies and a decrease in protected areas. Climate change variables have a moderate impact as the ranges analyzed are narrow. The regional application shows the feasibility of a European wide application.

JEL Classification: C25, Q15, Q18, Q24
Key words: land use transitions, land use drivers, discrete choice models

1. Introduction

European agricultural and environmental policies have affected land uses in Europe in the past, and future climate and bio-energy policies will further influence land use choices. In the last 20 years, the European Union has provided numerous subsides for encouraging specific land uses through the Common Agricultural Policy (CAP) and related reforestation and afforestations programs. Current concern about climate change, and the growing demand of land for bio-energy production, will likely increase incentives for reforestations and bio-energy uses in the future, therefore increasing land use competition.

Existing models predict that carbon sequestration in forests and bioenergy produced in Europe can contribute significantly to European climate policy (Ovando and Caparrós 2009). However, as explained in detail in Ovando and Caparrós (2009), existing land use models for Europe are either focused on the physical possibilities or Computable General Equilibrium models. These models typically do not consider factors which are relevant in explaining land-use transitions, such as landowners inertia to maintain current uses or liquidity constraints, the impact of non-commercial factors (bio-physical and environmental variables), the wish to retain options for future land-use decisions or any other benefits and costs associated to land uses of which the analyst is unaware. The main implication of ignoring these factors is that these models tend to overestimate the effects of land use changes, as confirmed by Stavins (1999), Lubowski et al. (2006) and Rashford et al. (2010). These authors performed econometric models of land use choice in the United States, but they did not explicitly accounted for bio-physical and environmental variables.

In this paper we present an econometric model that identifies and quantifies land use change drivers and estimates a reaction function for landowners in the agroforestry lands of the Andalusia region, located in the south of Spain. This region is a perfect pilot case, due to its large diversity, to evaluate the potential of this type of revealed preference model (which include monetary as well as non-monetary variables) to analyze and forecast the effect of potential scenarios on land use decisions. The results of the model will serve to assess the potential applicability of these models at European level given the resulting significance of the data used and their availability and aggregation at a larger scale.

Compared to previous models applied in the United States (Stavins 1999; Lubowski et al. 2006 and 2008; Rashford et al. 2010) our main contribution is the explicit analysis of non-monetary factors in explaining land use transitions and the identification of inertia effects on land use choice. Models including these non-monetary variables outperform models including only income and subsidies as explanatory variables. We use conditional logit but also nested and random parameter models in order to capture heterogeneity across observations. Ultimately, we estimate a reaction function that allows quantifying the impact on land use in four scenarios that target some of the model explanatory variables, such as climatic variable or subsidies received for specific land uses.

First we present the model description. Next econometric methods, materials and the case study are detailed, followed by the results of the analysis of the econometric models and their implications in different policy scenarios. We finish summarizing the main findings, drawing some conclusions and exploring future research allies.

2. Model description

We work with an econometric model based on landowner's revealed preferences about competitive agroforestry land uses in Andalusia (LUC-Andalusia model). We construct the model upon information on real land use choices and we measure the effects of different factors on the decision of allocating a parcel of land among three alternative land uses: crops, grass and forest. The model focuses on three groups of factors as potential drivers of land use decisions: (i) the market factors are represented by the landowner net income from specific land uses and associated production; (ii) the subsidy factors are represented by the government grants or payments addressed to specific land uses and associated production; and (iii) the environmental factors are represented by biophysical and environmental variables that lead landowners to choose land uses regardless of their commercial benefits, either due to personal preferences or to physical constraints. The goal is to obtain a reaction function of Andalusia agroforestry landowners that allocate parcels from their properties among three uses (crops, grass and forest) as a response to a change in these factors.

The micro-data[1] on observed land use decisions are obtained from the Corine Land Cover (CLC) database (Commission of the European Communities 1994). The explanatory variables are constructed using statistical and geographical information databases on commercial, subsidy, environmental and biophysical information associated to the analyzed land uses in Andalusia. We obtained these variables at parcel, municipality, province or region level, depending on their availability, and we assign them, using different criteria (see appendices), to the current and potential land uses in each observation. The analyzed years

[1] We collect data on land uses for specific parcels and not aggregated data by regions or large areas.

are 1990 and 2006 as the CLC provide data about real land use decisions in these two years. The CLC also provides data for year 2000 but we prefer to focus our analysis in 1990 and 2006 as this is the period for which more land use transitions are observed.

We simulate the likely evolution of a set of key explanatory variables in four scenarios and, based on the effects caused by changes in these explanatory variables, we use the model to predict the impact on the agroforestry land uses of the Andalusia region in each scenario. We set 2006 as our base year and we simulate the evolution of explanatory variables for the periods 2006-2022 and 2006-2038, as 16 years is the interval analyzed in the model.

3. Methodology

LUC–Andalusia is a probabilistic model that relies on panel data of cross-sectional observations of land parcels. It uses discrete choice econometric models to estimate land use transition probabilities based on a selected group of explanatory variables associated to the observed (chosen) and to the potential (not chosen) land uses.

3.1 Econometric specification

For modeling land use decisions, we assume a risk-neutral and price-taking agroforestry landowner that can allocate a parcel (i) of his/her property among a set of k alternative uses. The landowner chooses for parcel i the land use k that maximizes his/her utility (U_{ik}), given the landowner's expectations about the evolution of the benefits associated to each land use. We assume that landowners form their expectations about different land uses in the years previous to the moment in which the land use decision is observed. These expectations should include what landowners observe about the current land use in their parcel i and about the alternative land uses in the municipality where the parcel is located.

Apart from the benefits derived from market commodities, our model considers two additional factors that can play an important role in the landowner decision: subsidies (grants encouraging specific land uses) and biophysical and environmental attributes of the land. Subsidies are a component of the commercial benefits from the land use, but landowners perceive them differently than benefits from market transactions and could have a different impact in the model. Thus, we opt for separating it from market factors as a driver of land use transitions. Environmental and biophysical variables try to capture the non-pecuniary benefits that landowners obtain from the land and the physical constraints in some land use transitions that could explain land use choices independently of potential monetary benefits. This component includes amenities, socioeconomic and biophysical characteristics or other environmental characteristics associated to the observed parcels. They are recognized to have an important role on land use decisions on agroforestry lands (Lubowsky et al. 2006; Newburn et al. 2006; Campos et al. 2009).

The decision rule for the landowner is to choose the use with the highest utility at time t minus the current one-period expected opportunity cost of undertaking conversion. For K potential uses (j, k = 1,…,K), the landowner of a land parcel in use j chooses the use k at time t that provides the highest utility after conversion costs (Stavins 1999). We assume that the utility captures all benefits from the land both commercial and environmental.

$$\arg\max\left(U_{kt} - rC_{jkt}\right) \geq U_{jt}, \qquad [1]$$

where U_{kt} and U_{jt} represent the expected utility at time t for a parcel in use k and j, respectively; C_{jkt} is the expected marginal cost of converting that land parcel from j to k use at time t; and r is the discount rate (Lubowski et al. 2006).

We specify a landowner utility function for each land use k starting in use j in land parcel i at time t. This function includes both an observed (V_{ijkt}) and an unobserved (ε_{ijkt}) component characterized as a random error:

$$U_{ijkt} = V_{ijkt} + \varepsilon_{ijkt} \qquad [2]$$

Since the form of the U_{ijkt} function can be specified for each initial land use j and for each time period t, for simplicity we drop j and t for the functions, leaving us with a function of the form: $U_{ik} = V_{ik} + \varepsilon_{ik}$. The probability that the landowner chooses the land use k for parcel i (P_{ik}) over any land use h ($\forall\ h \in K$) is:

$$P_{ik} = P\left[U_{ik} > U_{ih}\right] = P\left[V_{ik} + \varepsilon_{ik} > V_{ih} + \varepsilon_{ih}\right] = P\left[V_{ik} - V_{ih} > \varepsilon_{ih} - \varepsilon_{ik}\right] \forall h \in K, \qquad [3]$$

This probabilistic problem can be solved using multinomial logit models. Depending on the error specification, we obtain different econometric specifications that estimate parameters for the explanatory variables in V_{ik}, which includes market (*MRK*), subsidy (*SUB*) and environmental variables (*ENV*). Thus, the V_{ik} function is:

$$V_{ik} = \alpha_k + \beta_k' MRK_{ik} + \lambda_k' SUB_{ik} + \eta_k' ENV_{ik} \,, \qquad [4]$$

where α_k is the specific intercept for the k^{th} land use; β'_k is the vector of market-related parameters for the k^{th} land use; MRK_{ik} is the matrix of the market-related explanatory variables for the i^{th} observation of the k^{th} land use; λ'_k is the vector of subsidy-related parameters for the k^{th} land use; SUB_{ik} is the matrix of the subsidy-related explanatory variables for the i^{th} observation of the k^{th} land use; η'_k is the vector of environmental-related parameters for the k^{th} land use; and ENV_{ik} is the vector of environmental-related explanatory variables for the i^{th} observation of the k^{th} land use. The parameters associated to the corresponding explanatory variables (β'_k for MRK, λ'_k for SUB, and η'_k for ENV) explain the probability of choosing land use k.

We estimate a different model for each one of the j starting land uses, as this reduces potential problems of heteroskedasticity, ending up with three models for the analyzed period. This implies that j is fixed in equations [2], [3] and [4] in each land use choice models. The variables that explain the probability of choosing the land use k are different depending on each of the starting land uses j in the previous year t-l, being l the interval of time between the years for which we have land use information.

Conditional Logit. If the errors are independently and identically distributed with an extreme value distribution across the h alternatives and i individuals, the probability model gives the conditional logit:

$$P_{ik} = \frac{\exp^{\mu V_{ik}}}{\sum_{h \in K} \exp^{\mu V_{ih}}} \,, \qquad [5]$$

where μ is the scale parameter (normalized to 1 in this model). The error distribution in the conditional logit implies that the ratio of the probabilities of choosing any two land uses is independent of the remaining land use alternatives. In other words, the unobserved component of the land use k function is independent of the unobserved error of land use h

function when choosing land use j. The violation of this assumption may arise in situations where some alternatives are qualitatively similar to others.

Nested Logit. The nested logit model groups alternatives in classes so that error terms are allowed to be correlated within the alternatives of the same class, but not between alternatives located in different classes. For our model, we group grass and forest uses in a class and crops uses in another class. We assume that grass and forest uses are closer substitutes between them than of crops since land quality requirements are more similar for them.

Thus, we set a no-crop (*NCR*) branch for grass and forest alternatives and a crop (*CR*) branch for the crop alternative. The latter is known as a degenerate branch (Louviere et al. 2000, pp. 153-154). In the nested logit model the probability of choosing alternative k from branch r (*NCR* or *CR*) is the product of two terms: the probability of choosing any of the land uses within branch r (P_{ir}) and the conditional probability of choosing land use k given the previous choice of branch r, ($P_{ik|r}$):

$$P_{ik} = P_{ir} * P_{ik|r} = \frac{\exp\left[V_{ir} + \lambda_r I_{ir}\right]}{\sum_{r\in R}\exp\left[V_{ir} + \lambda_r I_{ir}\right]} \frac{\exp\left[V_{ik}\right]}{\sum_{h\in K}\exp\left[V_{ih}\right]}, \qquad [6]$$

where I_{ir} is the inclusive value of the branch r and λ_r is the inclusive value parameter of branch r. The inclusive value is a measure of the expected maximum utility from the alternatives associated with the r^{th} class of alternatives. For the degenerate branch, the inclusive value parameter is fixed to 1 (Louviere et al. 2000, p. 154). The model offers estimations of the parameters associated to the explanatory variables as well as the of the inclusive value parameter

In the nested logit the scale parameter μ, previously shown in the conditional logit model, is confounded with the inclusive value parameter (λ_r). The inclusive value parameter is the ratio of the scale parameters associated to each class defined for this specific case of nested logit with two classes, one with a degenerate branch. A detailed explanation of the nested logit model can be found in McFadden (1981) and the particular case of the model with one-degenerate branch is discussed in Hunt (2000).

Random Parameters Logit. The random parameters logit model or mixed logit model (Train 1998) has the advantage of allowing for correlated errors terms and it does not assume the independence of irrelevant alternatives. This model also allows us to relax the assumption that all landowners have the same preferences over land use alternatives and it models unobservable heterogeneous landowners' preferences. The model allows for parameters to vary in the population. The error term is decomposed in an unobserved preference heterogeneity component and an alternative specific component. Thus, each landowner has his/her own vector of parameters $\left(\beta'_k, \lambda'_k, \eta'_k\right)$, which deviate from the population mean $\left(\bar{\beta}'_k, \bar{\lambda}'_k, \bar{\eta}'_k\right)$ by the vector $\left(\tilde{\beta}'_{ik}, \tilde{\lambda}'_{ik}, \tilde{\eta}'_{ik}\right)$. Thus, the function U_{ik} takes the following form:

$$U_{ijkt} = \left(\bar{\alpha}_{jkt} + \tilde{\alpha}_{ijkt}\right) + \left(\bar{\beta}'_{jkt} + \tilde{\beta}'_{ijkt}\right) MRK_{ijkt} + \left(\bar{\lambda}'_{jkt} + \tilde{\lambda}'_{ijkt}\right) SUB_{ijkt} + \left(\bar{\eta}'_{jkt} + \tilde{\eta}'_{ijkt}\right) ENV_{ijkt} + \varepsilon_{ijkt}, \quad [7]$$

where for each parameter we have a mean value and a deviation from that mean which is specific to each individual based on a distribution set a priori. If the distributional assumption about deviation parameters $\left(\tilde{\beta}'_{ik}, \tilde{\lambda}'_{ik}, \tilde{\eta}'_{ik}\right)$ and the ε_{ik} were the normal distribution, we would have the multinomial probit model. The consensus in the literature for the random parameter model is to assume an extreme value distribution for the ε_{ik} term, and to choose distribution for the random parameters, that in our case is assumed to be normal. In this model, the probabilities associated with the utility function have generally not a closed-form solution. However, recent simulation techniques allow for the estimation of this probability function.

The results from the preferred models obtained from these three different econometric specifications are shown in the main text. Appendix A shows the results from the remaining models (see below).

3.2 Case study

Our pilot study is the Andalusia region, which covers 17.2% of the country area, being the second largest region of Spain and surpassing the area of other European countries such as Austria. We selected this area because its scale allows to produce some additional data when needed, while most of the problems potentially arising in national-scale analysis are already prevalent.

Andalusia has a strong tradition in agriculture, livestock and forestry activities, and is part of the Mediterranean basin, a world region considered as a biodiversity hotspot (Myers et al. 2000). The forestry areas of Andalusia is the habitat of endangered species and endemism that cannot be found in other parts of the world. The savannah type forest with mixed trees, shrubs and grassland provides habitat to thousand of species. Its strategic position between the Mediterranean and the Atlantic sea makes this region a key area for bird migration from Europe to Africa. Natural and semi-natural land in Andalusia has been targeted by several protection figures in the last 30 years. This has resulted in that 19% of the total Andalusia area, and 35% of the total forest land area (including treeless grassland and shrublands) is protected (IECA 2011).

A unique feature of the Andalusia region is its variety of ecosystems. From the lowland crop fields of the *Guadalquivir* Valley, you find 300 km to the east the alpine mountain ecosystem of the *Sierra Nevada* mountains with a large ski resort and the highest peak mountain in continental Spain. Then, 50 km south you find the subtropical coast of Granada and 200 km east the *Tabernas* desert in Almería. Andalusia is also home of the Sierra de *Grazalema*, the area with the highest average rainfall in the Iberian Peninsula. This area is located southwest of Andalusia, along with the cork oak woodland of Cádiz a dense forest which houses the *canutos,* a subtropical forest habitat unique in continental Europe.

3.3 Materials

Several data sources have been employed to obtain the dependent and the explanatory variables for the model. Data have been gathered at parcel, municipality, province and region level to assign to each sampling observation values for the variables corresponding both to the observed and to the non-observed land uses. We assign real values to the explanatory variables associated to the chosen land use and potential values to the explanatory variables associated to the non-chosen land uses. In the Appendix B, we present a detailed description of the data collection process and the criteria used for assigning these values to the three land uses in each observation.

Dependent variable. We sampled from the Corine Land Cover (CLC) database (Commission of the European Communities 1994) 10,000 observation points from the Andalusia agroforestry land (crop, grass or forest uses) using *ArcGIS-ArcInfo 9.3.0* software. Each observation point corresponds to a land parcel (polygon in CLC terminology) classified by the CLC with a specific land use and characterized by an area (hectares) and a shape (meters). Appendix C reports the transformations made from the CLC land use categories to the land use classifications necessary for the LUC–Andalusia model (crop, grass or forest).

The land use information for the 10,000 sampling points has been gathered for the three years offered by the CLC database but we only use the observed land uses in 1990 and 2006.

We use as dependent variable in the model the land use observed for each sampled point in 2006 while the land use information from 1990 is used for constructing the subsamples of observations starting in the same land use. Thus, each sampling point is assigned a real land use choice k in 2006 and a starting land use j in 1990 according to the CLC codes and their corresponding land use categories in Appendix C.

Explanatory variables. For the explanatory variables, we gathered information about the landowner net income (*MRK* variables) and subsidies (*SUB* variables) associated to the different land uses at province and region level. Then we have constructed values for each municipality according to the observed predominant uses in these municipalities. For the environmental and biophysical characteristics (*ENV* variables) we have obtained data associated to the different sampling points either at parcel or at municipality level.

For the crop and grass MRK and SUB variables, we obtained data on farm net income (landowner net income at farm level) and subsidies (net of taxes) from the Farm Accountancy Data Network (FADN) (European Union 1999). These data are available for 14 categories of crop and livestock for the Andalusia region. When the FADN provides no data about a specific crop or livestock category, we have used the data from the *Red Contable Agraria (RECAN)* (MARM 2011), which is the Spanish branch of the FADN. The RECAN provides additional and more disaggregated data for some crops. These net income and subsidy figures were converted to € per hectare (using the average farm size from the FADN dataset). A detailed explanation of how these data have been collected, treated and assigned to each sampling point is presented in the Appendix B. This Appendix also shows the information on the 14 crop and livestock categories and how they match with the different crop and cattle types that have been identified to be predominant in the Andalusia municipalities.

For the forest MRK and SUB variables, we have identified the main forest species of Andalusia with commercial interest, resulting in nine (Appendix B). Then, we took the estimations of the net present value (NPV) associated to a entire rotation cycle for each of this forest species from different studies (Caparrós et al. 2001; Díaz-Balteiro 2002; Campos et al. 2008; Ovando et al. 2009 and 2010), and we annualized this NPV using a 5% discount rate. The obtained annualized figure is assigned to each corresponding species as the average annual net income (in € per hectare) from a forest stand with this species. The studies from Appendix B estimates this NPV with and without net subsidies so that we have estimates of the annualized net subsidies received by the landowner associated to each forest species. The NPV figure includes both the benefits from tree products and from livestock and game grazing rent from understory grass and shrubland. A detailed explanation of the estimation of these values and their assignment to each sampling point is presented in Appendix B.

For the ENV variables, we have gathered data at parcel level from different spatial databases using geographical information systems (AEMET 2011; Junta de Andalucía 2011; RAIF 2011; RIA 2011), and data at municipality level from official databases from the Andalusia Statistical Institute (IECA 2011). These databases refer to specific characteristics of the sampled point (parcel) when using GIS and to average characteristics of the municipality where the point is located when using official databases.

In addition to the area and shape of the parcel, and the municipality and the province where each observation point is located, the ENV variables obtained at parcel-level are: slope and altitude of the parcel, whether it is located in a public property, whether it is affected by any protection figure, and average rainfall (mm) and temperature (Cº) for the period 1990-2006. The ENV variables obtained at municipality-level using official databases are: population of the municipality, distance from the municipality to the main city in the province, municipality area (hectares) and number of population centers in the municipality. Appendix B offers a detailed description of the sources and procedures used to obtain these data and to assign them to the different sampling points.

4. Results

4.1 Sampling process

We generated 10,000 random geographic points over crop, grass and forest uses of the Andalusia territory that are linked to the information provided by CLC in 1990 and 2006. This layer has all CORINE classes, but it is referred geographical only to the studied land uses (class type 2 (crop uses) and class type 3 (forest and grass uses) in the Andalusia map). Over this layer we randomly drew 10,000 points and created a spatial link between the layer points and each one of the databases of CLC for years 1990 and 2006. The final output is a vector layer of points located in Andalusia with the information of classes 2 and 3 of CLC for years 1990 and 2006. We use the European CLC (CLC_N3) that works at three levels of disaggregation of land uses, because of its potential extension to a model at European level and for its availability for the two years in a homogeneous manner.

Resulting from the sampling process, we identified 62 points located in a parcel with a land use category that do not correspond to either crop, grass or forest. This could be caused by an error in the sampling process or by a change from either crop, grass or forest category in 1990 to a different category (developed, burnt or water) in 2006. Additionally, one point fell outside the Andalusia territory borders. These points are removed from the sample that is finally made of 9,937 observations.

Table 1. Share of crop, grass and forest land uses in Andalusia agroforestry lands from the sampling points (number of points and hectares associated to the land uses), from the Corine Land Cover complete database and from other sources of land uses in Andalusia

Land use	Sample (number of sampling points associated to the land use)		Sample (hectares associated to the polygons where the points are located)		All CLC polygons (code 2 and 3 relevant for our analysis (crop, grass or forest use))[1]		Land uses in Andalusia (Junta de Andalucía, 2008)[2]				Information System of Land Uses in Spain (SIOSE)[3]
	1990	2006	1990	2006	1990	2006	1995	1999	2003	2007	2005
Crop (%)	47.03	48.34	51.96	53.13	48.47	49.40	48.55	48.93	45.96	46.39	44.79
Grass (%)	19.25	17.88	16.67	15.96	18.47	17.22	19.83	19.46	20.70	20.46	19.20
Forest (%)	33.72	33.77	31.38	30.91	33.06	33.38	31.62	31.61	33.34	33.15	36.02

[1] Own elaboration based on Commission of the European Communities (1994).

[2] Own elaboration based on Junta de Andalucía (2008).

[3] Own elaboration based on Junta de Andalucía (2011).

Table 1 shows the shares of land uses among crop, grass and forest obtained from our sample of points, either by considering the number of points falling in each land use category or by considering the number of hectares for each land use category included in the parcels (polygons) containing the sample of points. In the first case we use the information provided by 9,937 points and in the second case we use the information provided by 3,642 parcels in 1990 and 3,789 in 2006. In both cases, crop accounts approximately for 50% of the land, forest for 30% and grass for 20%. Compared to all CLC polygons (8th to 10th columns in Table 1), our sample distribution among land uses is very similar, which imply that the sampling process represents our target population. The information from Junta de Andalucía (2008) is also very similar to the one from our sample and target population, while the SIOSE data (Junta de Andalucía 2011) gives more share of land use to forest and grass as compared to crop (Table 1). The differences with SIOSE could be pointing at some divergence between the two databases when categorizing a specific land use as crop, grass or forest.

4.2 Dependent variable: land use transitions

Table 2 offers the land use transitions between 1990 and 2006. This table shows the percentage of points that has transitioned from a land use in 1990 (rows) to a land use in 2006 (columns). The diagonal shows the proportion of the land use points that have not changed in the period.

At the end of the analyzed period, only 0.21% of the initial crop land use points have transitioned to other uses, while there has been important transition to crop from other uses, especially from grass. Grassland use suffers the major decrease, implying that 9.73% of this land use has changed to either crop or forest between 1990 and 2006, but with more transition to crops uses. Only 0.96% of the sampled points have moved to this use from crop or forest. The main transition from forest uses is to crop, but followed closely by transition to grass.

Table 2. Land use transitions for the period 1990-2006 for crop, grass and forest land uses in Andalusia. 9,937 sampling points

Initial land use (1990)	Final land use (2006)		
	Crop	Grass	Forest
Crop	99.79%	0.06%	0.15%
Grass	5.70%	91.17%	3.14%
Forest	0.95%	0.90%	98.15%

4.3 Land use models

For each starting land subsample use we present two models. Model I includes alternative specific constants for each land use alternative, and the net income and subsidies associated to each land use as explanatory variables. Model II incorporates additional environmental and biophysical variables. Thus, we are able to evaluate if the inclusion of these latter variables add to the explanatory power of the model and improve model assessment and prediction.

In order to test this, in model I we keep all the explanatory variables, independently if they are significant or not at a minimum 10% level of significance. In model II we present the models that offer the highest McFadden pseudo r^2, even if we have to maintain in the final model some variables not significant at the 10% level. The objective is to work with models as diverse as possible in terms of explanatory power without imposing excessive restrictions on the significance of individual variables that imply a reduction in goodness-of-fit.

Table 3. Conditional logit models for the three starting land use subsamples for the period 1990-2006

Variable	Crop initial use		Grass initial use		Forest initial use	
	Model I	Model II	Model I	Model II	Model I	Model II
	Parameters	Parameters	Parameters	Parameters	Parameters	Parameters
Crop land use						
Constant	9.6513	20.3504	-0.5357	-4.5220*	-0.9968	-7.6057**
Net income	0.0018	0.0034*	0.0001***	0.0001**	0.0002**	0.0002*
Subsidies	-0.0001	-0.0009	-0.0009	0.0009	-0.0054***	-0.0023
Protection figure		-1.7378**		-0.9245***		-0.3056
Slope		-0.0353*		-0.0351***		-0.0388**
Distance		-0.0017		0.0017		0.0034
Altitude				0.0006		
Ha municipality		1.7815E-05				-7.3129E-06
Public property		-1.6684***		-0.9618**		
Average temperature		-0.6161		0.2954**		0.5160***
Average rainfall		-0.0006		-0.0021***		-0.0034**
Grass land use						
Constant	-13.5810	-27.5199	1.3390*	-0.3475	1.3187	1.3925
Net income	0.0002	0.0005	-0.0001***	-0.0001**	-0.0004***	-0.0004***
Subsidies	0.0677	0.0480	0.0057	0.0067	-0.0128**	-0.0086
Protection figure		0.1492		0.2210		-0.3555
Slope		0.0415		0.0165***		0.0271**
Distance		-0.0069		0.0018		-0.0014
Altitude				0.0009***		
Ha municipality		5.5066E-06				7.1587E-07
Public property				0.3392		
Average temperature		0.6323		0.0707		-0.0710
Average rainfall		0.0104**		-0.0015***		0.0011
Forest land use						
Constant	3.9297	7.1695	-0.8033	4.8695**	-0.3219	6.2132***
Net income	0.0016	0.0075*	0.0047**	0.0020	0.0050	0.0085
Subsidies	0.0043	0.0171	0.0005	-0.0069*	0.0117**	0.0129**
Protection figure		1.5886*		0.7035***		0.6611**
Slope		-0.0061		0.0186**		0.0118
Distance		0.0086		-0.0035		-0.0020
Altitude				-0.0015***		
Ha municipality		-2.3322E-05				6.5970E-06
Public property		1.6684***		0.6226**		
Average temperature		-0.0162		-0.3661***		-0.4451***
Average rainfall		-0.0098**		0.0036***		0.0023**
n	4,607	4,597	1,907	1,897	3,340	3,321
McFadden pseudo r^2	0.041	0.322	0.041	0.152	0.069	0.153
AIC	0.035	0.031	0.691	0.627	0.205	0.190

Note: Model I includes only net income and subsidies as explanatory variables; Model II includes additionally biophysical and socio-demographic explanatory variables (ENV variables).
Asterisks (e.g.,***, **, *) denote significance at the 1%, 5% and 10% level, respectively.
n: number of observations.

We perform models for the three specifications explained in the methodology. In Table 3 we present the results for the conditional logit model. Appendix A shows the results of the Nested and the Random Parameter logit. We focus our analysis on the conditional logit models because the other two specifications, being more complex, do not significantly improve the prediction power and goodness of fit of the conditional logit models.

We find that crop net income increases the probability of transitioning from grass or forest to cropland uses, and forest net income increases the probability of transitioning from crop or grass to forestland uses. However, grass net income decreases the probability of transitioning from forest to grassland uses. Net subsidies has almost no impact in explaining transitions from crop or grassland uses to other uses, while the major impact they have in transitions from forestlands is in explaining the permanence in forest uses.

Table 4. Factors affecting transition probabilities (results from the conditional logit model II).

Final use	Initial use		
	Crop	Grassland	Forest
Crop	Net income (+)	Net income (+)	Net income (+)
	Protection figure (-)	Protection figure (-)	
	Slope (-)	Slope (-)	Slope (-)
	Public property (-)	Public property (-)	
		Temperature (+)	Temperature (+)
		Rainfall (-)	Rainfall (-)
Grassland		Net income (-)	Net income (-)
		Slope (+)	Slope (+)
		Altitude (+)	
	Rainfall (+)	Rainfall (-)	
Forest	Net income (+)		
		Subsidies (-)	Subsidies (+)
	Protection figure (+)	Protection figure (+)	Protection figure (+)
		Slope (+)	
		Altitude (-)	
	Public property (+)	Public property (+)	
		Temperature (-)	Temperature (-)
	Rainfall (-)	Rainfall (+)	Rainfall (+)

Protection figure has a positive impact in the transition to forest uses and a negative impact in the transition to crop uses. Similarly, slope decreases the probability of transitioning to crop, although in this case higher slopes favor transitions to both grass and forest. The altitude of the parcel, however, favors permanence of grassland uses but decreases the probability of moving to forest uses. In lands owned by public institutions or agencies, the probability of moving to forest is higher while the probability of transitioning to crop is lower. The climatic variables present opposite effects. Temperature affects positively to crop uses and negatively to forest uses. Rainfall, however, affects negatively to crop uses and positively to forest uses except when starting in crop uses, as in this case rainfall favors transitioning to grass. Table 4 presents a qualitative summary of all the significant land use drivers, and their signs, affecting land use transitions in the conditional logit model II.

4.4 Simulation scenarios

We present the likely evolution of five different key variables (net income, net subsidies, areas under protection figure, average temperature and average rainfall) from 2006 to 2022 (Table 5) and from 2006 to 2038 (Table 6) based on four hypothetical scenarios inspired on the *Intergovernmental Panel for Climate Change* (IPCC) scenarios (Nakicenovic et al. 2000), which are discussed and extended in Rounsevell et al. (2006) and in Kankaapää and Carter (2004), and on the three scenarios presented and discussed on Nowicki et al. (2009).

Scenario 1 represents the *business-as-usual* (BAU) situation where net income evolves similarly than in the period 1990-2006, with a 8% increase in real terms (Eurostat 2013). Subsidies evolve according to the baseline scenario described in Nowicki et al. (2009), which is interpreted as a reduction of 20% in crops, but maintaining the same subsidies for grass and forest due to climate change and biofuel policies. Protected areas remains stable as there is no expectations of increasing environmental protection policy in the BAU situation. Climate variables evolve as IPCC (2007) reflects if the current trend is maintained.

Scenario 2 follows the liberalization and rapid economic growth pattern described in scenario A1F1 in Nakicenovic et al. (2000) and in Nowicki et al. (2009). It resembles a market-based scenario implying a net income increase higher than in scenario 1 (higher for crop as compared to grass and forests) and a reduction in subsidies as in Nowicki et al. (2009). Due to increasing population and economic growth protected areas are reduced 2.5%. Climate variables as reflected in scenario A1F1 in IPCC (2007).

Scenario 3 presents a protectionist economy, as in scenario A2 in Nakicenovic et al. (2000), and in the conservative scenario from Nowicki et al. (2009). Income growth is moderate and drops as compared to the BAU situation. All subsidies are reduced 20% according to Nowicki et al. (2009) and protected areas are reduced according to scenario A2 from Nakicenovic et al. (2000). Climate variables evolve below the figures from the BAU situation, as expected due to a slower economic growth, and follow the values from the A2 scenario in IPCC (2007).

Table 5. Simulation results under different scenarios (changes from 2006 to 2022). Results for the conditional logit model II.

Variations in key variables	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	BAU	Liberalisation	Protectionist	Balanced
Crop net income (%)	8.00	15.00	2.00	4.00
Grass income (%)	8.00	10.00	2.00	6.00
Forest income (%)	8.00	10.00	2.00	6.00
Crop subsidies (%)	-20.00	-75.00	-20.00	10.00
Grass subsidies (%)	0.00	-75.00	-20.00	20.00
Forest subsidies (%)	0.0	-75.00	-20.00	20.00
Protection figure (%)	0.00	-2.50	-2.50	10.00
Temperature variation (ºC)	0.50	0.60	0.40	0.30
Rainfall variation (mm dav)	-0.10	-0.10	0.00	0.00
Resulting changes in land uses[1]				
Crop (%)	1.09	4.11	1.56	0.58
Grass (%)	-1.13	1.51	-1.19	-0.68
Forest (%)	0.04	-5.62	-0.38	0.10

[1] Percentages of changes refer to the total area.

Scenario 4 resembles a balanced economy based on the B1 scenario from Nakicenovic et al. (2000). Income generation is moderate but compatible with green growth. Subsidies increase for all uses but more for grass and forest due to incentive to biofuel production and climate change mitigation. Environmental protection is encouraged resulting in an increase in protected areas. Climate variables follow the evolution described for scenario B1 in IPCC

(2007), which implies a drop in values as compared to the BAU situation due to a successful climate change mitigation policy.

According to the conditional model II, the simulation scenarios for the period 2006-2022 (Table 5) show that there are no large changes in land use, except in scenario 2. Crops are favored in all scenarios as in none the increase in subsides to grass and forest is high enough to reduce crop uses. Indeed, the scenario with highest drop in subsides (scenario 2) is the one implying a major increase in crop uses and an important reduction of the area covered by forest. Climate change variables have a moderate impact on land use transitions as the ranges analyzed are narrow, as it can be expected for the time horizon analyzed.

Even in the simulation scenarios up to 2038 (Table 6), we obtain modest changes, with most uses changing less than 2% of the total area. Again, the sole exception is scenario 2, where forest would decline about 10%.

Table 6. Simulation results under different scenarios (changes from 2006 to 2038). Results for the conditional logit model II.

Variations in key variables	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	BAU	Liberalisation	Protectionist	Balanced
Crop net income (%)	16.0	30.0	4.0	8.0
Grass income (%)	16.0	20.0	4.0	12.0
Forest income (%)	16.0	20.0	4.0	12.0
Crop subsidies (%)	-40.0	-100.0	-20.0	20.0
Grass subsidies (%)	0.0	-100.0	-20.0	40.0
Forest subsidies (%)	0.0	-100.0	-20.0	40.0
Protection figure (%)	0.0	-5.0	-5.0	20.0
Temperature variation (ºC)	1.0	1.2	0.8	0.5
Rainfall variation (mm dav)	-0.2	-0.2	0.0	0.0
Resulting changes in land uses[1]				
Crop (%)	1.20	6.24	1.60	-1.41
Grass (%)	-1.14	4.21	-1.17	1.11
Forest (%)	-0.06	-10.45	-0.44	0.30

[1] Percentages of changes refer to the total area.

5. Discussion and concluding remarks

The econometric model presented analyzes land use choices in Andalusia based on real land use decisions made by landowners and managers between 1990-2006. The model does not assume that land use transitions occur when returns from an alternative land use exceed the ones from the current land use. Instead, it observes when land use transitions have occurred in the past and quantifies the probability that selected drivers (using proxy variables) have had a significant impact in that transition. Thus, this approach takes into account landowners inertia or liquidity constraints that explain why they keep their land uses, non-commencial values (aestethics and recreation) which are reflected in some of the biophysical and environmental variables (for example, slope or protection figure as proxy of landscape view or proximity to significant natural assets), and benefits and costs of which the analyst is unaware, that are considered in the error term of the econometric model.

We find that inertia has a limited effect in explaining land use decisions and that there is more significance coming from monetary and non-monetary factors. In the econometric models this is partially reflected in the parameters corresponding to the alternative specific constant for the starting land use in each corresponding model, which are not always significant. Landowners and managers probably need long periods of time to react to new incentives or market conditions but the effect of physical and environmental factors seems to be more important in the decision. Among the studied land uses, grassland is the one that present the highest probability of change.

Although net income and subsidies are relevant factors in some of the models, the significant increase in the model goodness of fit when including biophysical and environmental variables indicate that land use transitions are largely explained by non-monetary factors as compared to monetary factors. Inclusion of additional biophysical and environmental variables could increase the significance of the model and identify additional drivers that could be specific to the analyzed areas.

The scenarios for the period 2006-2022, or even for the period 2006-2038, show that there are no large land use changes, except in the scenario that resembles a liberalized economy with rapid growth. Crops are favored in all scenarios as subsidies for grass and forest are low or decreasing. Forest increase in scenarios 1 and 4, presumably due to the increase or maintenance of subsidies and protected areas, but to a small extent in both cases. In scenario 2, the suppression of all kinds of subsidies and the reduction in protected areas imply a relevant reduction of the area covered by forests that leads to the only scenario where grassland increases. Climate change variables have a moderate impact in our scenarios, but they are significant in most of the models.

In summary, the Andalusia pilot study shows that policy makers should take into account environmental and bio-physical factors, and inertia to a lesser extent, when designing land use policies, with carbon sequestration policies and bio-fuel production as prime examples. If the goal of policy makers is to promote uses associated to these policy goals, they have to take into account that even if incentives are high, physical constraints and environmental preferences could make landowners not to decide to change to a more profitable. These non-monetary factors are at least as important as net income and subsidies in land use change decisions.

The other goal of this paper was to assess the feasibility of extending the methodology to the rest of Europe. The regional application has shown the feasibility of an extension to the rest of Europe with existing data, except in the case of forest income and subsides (which, however, have turned out to be non-significant in most of the models). Thus, the potential of this approach is promising and at the European level it could be an important tool for land use policy design.

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APPENDIX A: Nested and Random Parameters logit models

Tables A.1 and A.2 presents the results of the nested logit models and the random parameters logit models.

Table A.1 Nested logit models for each starting land use samples for the period 1990-2006

Variable	Crop initial use		Range initial use		Forest initial use	
	Model I	Model II	Model I	Model II	Model I	Model II
	Parameters	Parameters	Parameters	Parameters	Parameters	Parameters
Crop land use						
Constant	1.5295***	13.2367***	-1.3571*	-5.1222**	-0.9361	-7.1281**
Net income	0.0020	0.0032*	0.0001***	0.0001**	0.0002	0.0002
Subsidies	-0.0006	-0.0005	-0.0009	0.0010	-0.0054***	-0.0025
Protection figure		-1.6553***		-1.0719***		-0.3123
Slope				-0.0453***		-0.0354**
Ha municipality		-1.9187E-05*				-7.4632E-06
Public property		-1.5785***		-1.1955**		
Average temperature				0.2593**		0.4980***
Average rainfall		0.0012		-0.0014*		-0.0036*
Grass land use						
Constant	-1.1202***	-10.2925	1.8706*	0.5931	1.3466	1.7608
Net income	0.0000	-0.0001	-0.0002***	-0.0002***	-0.0005	-0.0003
Subsidies	-0.0003	-0.0369	0.0061	0.0085	-0.0144	-0.0069
Protection figure				0.3280		-0.2482
Slope				0.0225***		0.0238*
Altitude				0.4134***		
Ha municipality		1.9187E-05*				1.4906E-06
Public property				0.0011		
Average temperature				0.0591		-0.1076
Average rainfall				-0.0016***		0.0014
Forest land use						
Constant	-0.4093***	-2.9442	-0.5135	4.5291**	-0.4104	5.3673**
Net income	0.0000	0.0075*	0.0052**	0.0031	0.0059	0.0063
Subsidies	0.0001	0.0205**	0.0012	-0.0053	0.0129	0.0102
Protection figure		1.6553***		0.7439***		0.5605
Slope				0.0228***		0.0116
Altitude				-0.0011***		
Ha municipality						5.9726E-06
Public property		1.5785***		0.7821**		
Average temperature				-0.3184***		-0.3904***
Average rainfall		-0.0012		0.0030***		0.0022*
Inclusive value parameter for NCR branch	105.3737	25.9494***	0.5359**	0.2563	1.1256	0.7916
n	4,607	4,607	1,907	1,897	3,340	3,321
McFadden pseudo r^2	0.0639	0.2330	0.0427	0.1548	0.0690	0.1523
AIC	0.0353	0.0314	0.6913	0.6237	0.2011	0.1902

Asterisks (e.g.,***, **, *) denote significance at the 1%, 5% and 10% level, respectively; n: number of observations.

Table A.2 Random Parameter logit models for the three starting land use samples for the period 1990-2006

Variable	Crop initial use		Grass initial use		Forest initial use	
	Model I	Model II	Model I	Model II	Model I	Model II
	Parameters	Parameters	Parameters	Parameters	Parameters	Parameters
Crop land use						
Constant	47.3693	7.1111	0.8788	-6.0281***	23.0793*	-7.2299**
Net income	0.2824***	0.0286*	-0.0009	0.0000	0.0043*	0.0003*
Subsidies	-0.1489	-0.0088	-0.0090	-0.0019	-0.1209***	-0.0027
Protection figure		-0.8036		-2.6831*		-0.4908
Slope						-0.0948*
Distance						0.0040
Average temperature				0.3201***		0.4968**
Average rainfall		-0.0021		-0.0023***		-0.0039**
Grass land use						
Constant	-31.1537	-18.2387	0.6168	7.3699***	44.5776**	1.5776
Net income	-0.0005	0.0006	-0.0002	-0.0001***	-0.0409***	-0.0020
Subsidies	-0.0815	0.0355	0.0071	0.0062	-0.1355	-0.0077
Protection figure				1.6182		-0.3441
Slope						0.0436**
Distance						-0.0023
Average temperature				-0.2711***		-0.0578
Average rainfall		0.0189**		-0.0013***		0.0017
Forest land use						
Constant	-16.2157	11.1276	-1.4956	-1.3418	-67.6568**	5.6523**
Net income	0.0133	0.0034	0.0052	0.0035	0.0837	0.0080
Subsidies	0.0314	0.0137	0.0012	-0.0050	0.3463***	0.0128*
Protection figure		0.8036		1.0649**		0.8349**
Slope						0.0512
Distance						-0.0016
Average temperature				-0.0489		-0.4389***
Average rainfall		-0.0167***		0.0036***		0.0023**
Standard deviation parameters						
Crop land use						
Constant					16.4656***	
Net income	0.0819	0.0076*	0.0011	0.0001	0.0017	
Subsidies	0.0282		0.0058	0.0029	0.0415***	0.0372*
Protection figure				1.5017*		
Grass land use						
Constant	27.7029					
Net income					0.0166***	0.0009*
Forest land use						
Constant	11.6463					
Subsidies					0.1340***	
Protection figure		3.3977				
Average rainfall		0.0002				
n	4607	4,607	1,907	1,907	3,340	3,321
McFadden pseudo r^2	0.1252	0.2312	0.0467	0.1091	0.0954	0.1638
AIC	0.0346	0.0318	0.6894	0.6510	0.1978	0.1884

Asterisks (e.g.,***, **, *) denote significance at the 1%, 5% and 10% level, respectively; n: number of observations.

APPENDIX B: Data collection and treatment

B.1 Crop data

For assigning a value of commercial net income of crop uses to a specific parcel and their corresponding sampling points, we work with data on crop commercial net income at municipality level. We construct an indicator of crop commercial net income for each municipality based on the three main crops cultivated in the municipality and on the net income from these three crops. Once a commercial net income indicator for each municipality is calculated, we assign them to each observed point considering the municipality where the point is located.

First, we identify for the available years of our time series the two main crops for each municipality out of the four categories of crop established in IECA (2011): irrigated arable crops, non-irrigated arable crops, irrigated woody crops, and non-irrigated woody crops. The main crops are selected based on the average cultivated area for the crop respect to the total cultivated area of the municipality in the considered period (1990-2006). Thus, for each municipality we first identify eight main crops for each year of our time series for which there is available data.

Then, for each municipality we select the three main crops out of these eight that occupy the largest area (hectares) of cultivated land in the period in the municipality. These data have been gathered from IECA (2011) and are only available from 1995 to 2006 so that we assume that data from 1995 to 2006 is similar to data from 1990 to 2006. We select the three main crops in each year since these three crops represent in most of the cases more than 90% of the total cultivated area in the municipality in the year. When the main or the two main crops represents more than 90% of the cultivated area, we only consider these crops, removing those that contribute marginally to less than 10% of the cultivated area of the municipality. These calculations are done under the assumption that expectations about crop net income are formed without considering the marginal crops cultivated in the municipality. We obatined a total of 89 crops to estimate the market (MRK) and subsidies (SUB) variables for the crop uses in our model.

The resulting crops were classified and assigned to the 14 group categories of crops employed by the European FADN (Farm Accountancy Data Network) (European Union

1999) and by the Spanish RECAN (National Agrarian Accounting Data Network)[2] (MARM 2011a), which is the Spanish branch of the FADN.

For the market data, we obtain the farm net income (without subsidies) associated to different crops in the Andalusia region from the FADN (European Union 1999). These data provide a figure of crop net income in € per hectare for the 14 different crop types for each year of the period. Table B.1 shows the 89 crops considered for the Andalusia municipalities in our data collection and how they match with the FADN and RECAN crop grouping that allows for assigning a net commercial income to each crop considered in our database.

Thus, we end up with an estimation of net commercial income for each one of the main cultivated crops and with a quantity of hectares cultivated in average for three of these crops in the period in each municipality. To obtain a final figure of crop net income for the municipality we estimate a mean of the net income of these main crops weighted by the cultivated area for each crop. Conversion costs are considered marginal for this land use.

As the FADN does not provide information of net income both for codes 31 (Specialist wine) and 34 (Permanent crops combined) crops, we obtain data at national-level for the RECAN database (MARM, 2011a)[3] for these two cases. The RECAN distinguishes crop code 31 between Specialist wine for wine production and grape production. Crop for raisin production is not available at any level, which implies missing 83 observations out of the 9,937 sampling points. We accept working with these missing values since they only represent 0.84% of the sample.

Subsidies data for crop production are taken also from the FADN using the same categories. This provides us with a monetary value of the net subsidies (subsidies net of taxes as provided by FADN databases) associated to a specific crop. Data on net subsidies are averaged over the different analyzed periods and assigned to the different crops considered for the calculation of the municipality crop net income. Then, we calculate the crop net subsidies for a specific municipality as a weighted mean of the subsidies values for the main crops cultivated in the corresponding period in each municipality. After that, each observed parcel is assigned a net subsidy value for crop uses taking into account the municipality where the parcel is located. The net subsidies considered from the FADN database are both balance subsidies and taxes on investments (SE405 code in FADN) and balance current subsidies & taxes (SE600 code in FADN) (European Union 1999).

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[2] *Red Contable Agraria Nacional.*

[3] Data for years 1995, 1997 and 2006 are not available from the RECAN.

Table B.1 Classification and matches of FADN crop categories with the 89 main crops identifies in the Andalusia municipalities for the LUC - Andalusia model

COD TF 14 (FADN)	FADN TF 14 GROUPING	TYPE OF FARMING (FADN)	CROPS IDENTIFIED FOR THE LUC-ANDALUSIA MODEL
13	Specialist cereals, oilseed and protein crops (COP)	Specialist crop (other than rice) (131), Rice (132) and COP and rice combined (133)	Alfalfa, carob tree, lupin, rice, oat, peanut, barley, rye, winter cereals for forage, rape, einkorn wheat, chickpea, sunflower, dry pea, dry broad bean, dry common bean, lentil, maize, fodder maize, forage sorghum, tranquillon and other mixtures, clover, wheat, triticale, vetch, forage vetch and bitter vetch.
14	Specialist other fieldcrops	Specialist root crops (141), cereals and root crops combined (142), specialist field vegetables (143), specialist tobacco (1441), specialist cotton (1442) and various field crops combined (1443)	Cotton, cardoon and other forages, cumin, liquorice and others, broad bean, pea, lupin, alfalfa, carob pods and others, extraearliest potato, earliest potato, average potato station, later potato, grasslands, sugar beet, tobacco and total land occupied by arable crops.
20	Specialist horticulture	Market garden vegetables-outdoor (2011), market garden vegetables-under glass (2012), market garden vegetables outdoor and under glass combined (2013), flowers and ornamentals-outdoor (2021), flowers and ornamentals-under glass (2022), flowers and ornamentals outdoor and under glass (2023)	Garlic, anise, eggplant, pumpkin and zucchini, sugarcane, onion, carnation, cauliflower, asparagus, green pea, green broad bean, green common bean, lettuce, melon, other flowers, other vegetables, cucumber, pepper, ornamental plants, watermelon and tomato.
31	Specialist wine	Vineyard for quality wine (311), specialist vineyards for table grapes (3141) and vineyards for raisins (3142)	Vineyard (for table grapes), vineyard (grapes to raisins), vineyard (grapes for wine), occupation associated - Vineyard (for table grapes), occupation associated - Vineyard (grapes to raisins) and occupation associated - Vineyard (grapes for wine)
32	Specialist orchard - fruit	Fresh fruits (other than citrus) (3211), nuts (3212), fresh fruits and nuts combined (3213), citrus fruits (322) and fruits & citrus fruits combined (323)	Avocado, almond tree, jujube, apple guava, japanese persimmon, raspberry, currant, black mulberry and others, wild cherry tree and sour cherry tree, chirimuya, prickly pear, plum tree, strawberry and garden strawberry, pomegranate tree, common fig, lemon tree, mandarin tree, apple tree, peach tree, orange tree, bitter orange tree, loquat, walnut tree and pear tree.
33	Specialist olives	Olives (330)	Olive tree (for olive oil) and olive tree (for table olives)
34	Permanent crops combined	Various permanet crops combined (340)	Lands occupied by woody crops

All monetary data used in our models are converted to 2006 prices. We use IPC deflator to update to 2006 Euros data for years different than 2006 (INE 2011).

B.2 Grass data

For grass uses, the procedure of estimating the commercial net income and subsidies has been very similar to the one used for crops. In this case, instead of main crops cultivated in each municipality, we have obtained information on Livestock Units (LU)[4] and number of heads per livestock type per municipality. These data have been obtained from IECA (2011). We work with bovine, ovine and porcine livestock Units (LU), discarding those relating to equine, fowl and rabbit units. There are only data available for the years 1989 and 1999 about number of livestock units. The average of both years is considered for our analysis.

Data on commercial net income associated to livestock operations are available only from the Spanish RECAN since the European FADN do not provide values for the codes referred to livestock operations for the Andalusia region. Thus, we have estimated the commercial net income in € per hectare for the period 1996-2006 from the RECAN (MARM 2011a). Conversion costs are considered marginal for this land use.

Subsidies data for livestock operations are also taken from the RECAN and assigned similarly than net commercial income. This provides us with a monetary value of the subsidies associated to a livestock type and an average data on livestock subsidies per municipality. Data on subsidies are averaged over the analyzed period and assigned to the different livestock operations considered for the calculation of the municipality net commercial income. Thus, we calculate the livestock subsidies for a specific municipality as a weighted mean of the subsidies for the main livestock units present in the corresponding period in each municipality. Each observed parcel is assigned the subsidy value of the municipality where the point is located.

Table 1.1 shows the correspondence between RECAN codes and livestock operations in Andalusia. The subsidies considered from the RECAN are the same than the ones considered for crops from the FADN.

B.3 Forest data

[4] A livestock unit is cow with 500 kg of weight. It is the common livestock carrying capacity unit used in Spain.

For assigning a value of commercial net income of forest uses to a specific parcel and their corresponding sampling points, we work with data on forest commercial net income at municipality level. Same as with crop and grass, we build an indicator of forest commercial net income for each municipality based on the three main forest species present in the municipality and on the net income from these three forest species. Once calculated a forest commercial net income for each municipality, we assign them to each observed point considering the municipality where they are located.

The identification of the main forest tree species in each one of the municipalities of Andalusia has been made through the use of *ArcGis (version 10.0)* software. We have integrated the information relative to the Andalusia municipalities with the information of the Spanish Third Forestry Inventory (IFN3) (MARM 2011b). The IFN3 information was collected between 1997 and 2006.

The projected coordinate system employed for the treatment and generation of geographical information has been ED 1950 UTM 30 N, resulting in eight GIS projects, one per Andalusia province. For each province we have selected, out of all present forest tree species, those that have commercial interest. The species with commercial interest in Andalusia are: holm oak (*Quercus ilex)*, cork oak *(Quercus suber)*, aleppo pine *(Pinus halepensis)*, european black pine *(Pinus nigra)*, rodeno pine *(Pinus pinaster)*, stone pine *(Pinus pinea)*, scotch pine *(Pinus sylvestris)*, eucalyptus *(Eucaliptus sp.)* and poplar *(Populus sp.)*. The genus *Eucaliptus sp.* is considered, from the point of view of net income estimation, formed by all eucalyptus species present at province-level, along with the polygons formed by a mix of eucalyptus species. In the case of the poplar, we have considered *Populus alba*, *Populus nigra* y *Populus x canadensis* as a single group.

The estimations of areas covered by these tree species has been made considering the species classified as number 1 (ESP1) in the IFN3; that is, by considering those species that are dominant in the area of the polygon and not using species with less degree of occupancy in the area (canopy cover), which are considered accompanying species (ESP2 and ESP3). The total surface occupied in each municipality by the selected forest tree species is calculated as the sum of the hectares of all polygons identified with these species. Finally, we select for each municipality the three tree species that occupy the longest area of the total occupied by all tree species in the municipality. Thus, we end up with three main tree species and their corresponding surface area for each municipality. We assume that expectations of landowner about potential net income from forest uses are formed considering the most predominant tree species in the municipality where their land parcel is located.

For assigning commercial net income to each of the 9 commercial tree species, we use the estimations of different studies about the net present value associated to a full-cycle of a stand of each of this tree species. These studies are the following: for data on holm oak we use the results from Campos et al. (2008); for data on cork oak we use the results from Ovando et al. (2009); for data on stone pine and eucalyptus we use the results from Ovando et al. (2010); for data on scotch pine we obtain estimations based on Caparrós et al. (2001); for data on poplar we use the results from (Díaz-Balteiro, 2002); and for data on aleppo pine, european black pine and rodeno pine we obtain estimations based on the scotch pine data from Caparrós et al. (2001).

The obtained NPV has been annualized using a 5% discount rate, and we have assigned the annualized figure as the average annual net income from a forest stand with the corresponding tree species. This NPV is estimated in these studies with and without subsidies so that we also have estimates of the annualized subsidies of the forest landowner associated to a specific tree species. The NPV figure includes both the benefits from tree products and from livestock and game grazing rent (understory grass and shrubland). The average forest net income have been assigned to each sampling point according to the forest species predominant in the municipality where the point is located, following a procedure similar to the one used for crop and grass net income and subsidies value assignment. Conversion costs to forest land are included in the NPV since this figure considers the complete cycle of a forest stand, including the preparatory works for transitioning to forest uses.

Since these studies refer to a single year, we need additional information to create a time series of the annualized net income and net subsidies for each forest tree species for the period of analysis. For that purpose, we create a database of prices for the main commodities obtained from each of the 9 considered tree species. These database of prices have been created for the period 1994-2009 and price variation indexes are created for the time series and then applied to the net income figures. These prices have been collected from Junta de Andalucía (2011a and 2011b).

We have completed a time series for 14 forestry species. For the holm oak, we offer prices for firewood, and for cork oak we offer prices for cork (both standing and at farm gate). Prices for timber devoted to saw and pole are gathered for Aleppo pine, European black pine, rodeno pine, Stone pine, Scotch pine, eucalyptus and poplar. For Rodeno pine and eucalyptus we also gathered information of prices of timber devoted to wood grinding. For the Stone pine, we also obtained prices for the pine nut (*piñon*). Timber prices are expressed in euros/m^3 regardless what is the destiny (saw or grinding). The unit for firewood, cork and pine nut is euros/100 kg.

B.4 Environmental and biophysical data

For the *ENV* explanatory variables, we generate a set of variables of biophysical, socioeconomic and climatic type for the 9,937 sampling points. Variables are obtained either at parcel level, defined by their UTM coordinates, and at municipality level defined by the average value of the variables for the municipality where the point is located.

Information gathered at point-parcel level refers to biophysical and environmental variables and is provided by several GIS databases. To extract the information for each parcel from GIS databases we use the *ArcGIS 10.0* software. Information gathered at municipality level refers to territorial and socio-demographic variables and is provided by the Andalusia Statistics and Cartography Institute (IECA 2011).

The selection of parcel-level biophysical and environmental variables has been made based on the available GIS databases. The information is considered appropriate if it explains the physic and climatic reality of Andalusia agroforestry areas for the studied period. Apart from identifying the municipality and the province where each observation parcel is located, which provides key information for building the remaining explanatory variables of the model, the selected variables are: (i) the slope where the point is located, expressed in %; (ii) altitude above sea-level (meters), obtained through the use of a digital elevation model; (iii) protection figure, which determines whether the sampling point is included within a protected land area or not, such as Protected Natural Areas**,** Areas of Special Conservation Interest and Special Protection Area for Birds. We use this information to construct a dummy variable that takes value 1 when the point is in a parcel under some type of protection figure.

The base cartography has been of vector and raster type, obtaining and generating the information in numerical and graphical format. The data sources are: (i) Digital Elevation Model (*Modelo Digital de Elevaciones (MDE)*) provided by the Unit of Geographical Information Systems of the Spanish National research Council (CCHS-CSIC) (the elevation model consists of two layers of elevation information in raster format); (ii) map of slopes of the Andalusia region created by the Unit of Geographical Information Systems of the Spanish National research Council (CCHS-CSIC); and (iii) the vector layers on the Andalusia Natural Protected Network (RENPA) from the REDIAM (Junta de Andalucía 2011c).

Some points fall outside of the limit of the employed vector or raster layers for the different variables and have no information associated with the corresponding variable, implying some missing values for no more than six observations in the sample.

Data search on climatic variable is not available for the whole period for which we have data from the remaining explanatory variables. For being able to have a complete time series data for these variables we have proceeded as follows.

For the period 1995-2000, we gathered the data for the precipitation and temperature vector layers available on Junta de Andalucía (2011c), by treating graphical and alphanumeric information with GIS tools (*ArcGIS 10*), as explained above. The information associated with the temperature is annual average temperature. For precipitation we gathered data on annual average total precipitation. This data was observed for each sampling point.

For the period 2001-2006, data was not directly available and has been generated using GIS tools. The process for generating these data consisted in finding a set of weather stations representative of the Andalusia territory, accounting for variations associated with the topography. The criterion followed to select a station is governed by a spatial and by a dataset criterion. The spatial criterion refers to the geographic location of weather stations (UTM coordinate) and to the altitudinal distribution of its position[5]. The criterion is that we choose the stations for which we obtain the data so that they are distributed evenly over the surface of study and reflect the variations of the variables in the elevation direction. The criterion also involves that we have data for a minimum number of years in the analyzed period from the station. Thus, in the case of two close stations with similar elevation, we select only the one with the most complete dataset as representative of the climatic conditions prevailing in the area. However, when two or more stations are close to each other in distance and elevation, but are located at different altitudinal levels, we consider both for the data collection. The minimum number of years we require from a weather station is at least four years in the period 2001-2006 for which we need to collect data following this procedure. With the above criteria, the total number of weather stations selected is shown in Table B.2.

The data from the weather stations have been obtained from various meteorological observation networks (AEMET 2011; RAIF 2011; RIA 2011). For creating the climatic variables we have used the Geographic Information System software *ArcGIS 10.0*. We

[5] The weather stations considered to estimate meteorological models was extended to the Portugal and Spanish provinces with frontier with Andalusia. This was intended to represent the variations of meteorological variables as real as possible since the climatic characteristics of some of the sampling points could be closer to these weather stations not located within the Andalusia borders.

generated a layer of points associated with the different weather stations, including the climatic information. The association of values to each of the 10,000 sampling points was done by interpolating the values of the weather stations, creating a model of average temperature and rainfall for the total area of Andalusia. The method used for interpolation is IDW (Inverse Distance Weight), a tool available in the ArcGIS 10.0 software. We have obtained the climatic variable values for each of the 10,000 sampling points using a raster model. The result is a database containing values for mean annual temperature and mean annual precipitation for the periods 1995-2000 and 2001-2006. Values for the period 1995-2006 are calculated as the mean of the values from these two periods.

Table B.2 Number of selected weather stations and total stations.

Province	Weather Stations
Almería	12
Cádiz	11
Córdoba	19
Granada	19
Huelva	14
Jaén	19
Málaga	13
Sevilla	23
Andalusia	130

The selection of socio-demographic variables has been made based on the statistical data available at municipality level in IECA (2011). The information is considered appropriate if it provides relevant data on the social, demographic and economic characteristics of the municipality where the sampling point is located in some of the years of the analyzed period. The selected variables are: population (number of habitants per municipality in years 1996, 2000 and 2006), area (hectares of the municipality area), distance to the province capital (kilometers from the municipality where the point is located to the capital of the province of the municipality), and centers of population (town/cities/villages in the municipality where the sampling point is located).

APPENDIX C: Corine and LUC-Andalusia land uses

Table C.1 Correspondence of Corine (CLC) land uses with LUC-Andalusia land uses

CORINE CODE	CORINE LAND USE	LUC–ANDALUSIA LAND USE
111	Continuous urban fabric	Developed
112	Discontinuous urban fabric	Developed
121	Industrial or commercial units	Developed
122	Road and rail networks and associated land	Developed
123	Port areas	Developed
124	Airports	Developed
131	Mineral extraction sites	Developed
132	Dump sites	Developed
133	Construction sites	Developed
141	Green urban areas	Developed
142	Sport and leisure facilities	Developed
211	Non-irrigated arable land	Crop
212	Permanently irrigated land	Crop
213	Rice fields	Crop
221	Vineyards	Crop
222	Fruit trees and berry plantations	Crop
223	Olive groves	Crop
231	Pastures	Grass
241	Annual crops associated with permanent crops	Crop
242	Complex cultivation patterns	Crop
243	Land principally occupied by agriculture, with significant areas of natural vegetation	Crop
244	Agro-forestry areas	Forest
311	Broad-leaved forest	Forest
312	Coniferous forest	Forest
313	Mixed forest	Forest
321	Natural grasslands	Grass
322	Moors and heathland	Grass
323	Sclerophyllous vegetation	Grass
324	Transitional woodland-shrub	Forest
331	Beaches, dunes, sands	Water
332	Bare rocks	Grass
333	Sparsely vegetated areas	Grass
334	Burnt areas	Burnt
335	Glaciers and perpetual snow	Water
411	Inland marshes	Water
412	Peat bogs	Water
421	Salt marshes	Water
422	Salines	Water
423	Intertidal flats	Water
511	Water courses	Water
512	Water bodies	Water
521	Coastal lagoons	Water
522	Estuaries	Water
523	Sea and ocean	Water

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