Resources, Conservation and Recycling 106 (2016) 1–8

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Determinants of behavior toward selective collection of batteries in Spain. A bivariate probit model

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ARTICLE INFO

Article history:
Received 21 May 2015
Received in revised form 3 November 2015
Accepted 4 November 2015
Available online 19 November 2015

Keywords:
Batteries recycling behavior
Waste management
Bivariate probit model
Marginal effects

ABSTRACT

The purpose of this paper is to identify the decision-drivers that affect the recycling efforts of Spanish individuals through the separate collection of batteries. To this end, we have carried out an empirical study using a bivariate probit model, where the dependent variable we want to analyze is the household attitude to recycling batteries, which we explain through a set of attitudinal and socio-economic factors, together with an endogenous factor representing the environmental concern of the individuals. The results of this estimation suggest that the respondent's concern for the environment is a very significant factor influencing the recycling of batteries. In general, the profile of individuals with higher probability of recycling batteries is an individual born in Spain, with a high level of income, student, living in a large city and who had knowledge of any environmental campaign in the last year. Another important result is that the probability of recycling increases with age, but this increases becomes smaller as the individuals get older until the age of 62. From 63 years old, an additional year reduces the probability of recycling. The results obtained would be useful in designing measures based on the characteristics of individuals in order to improve existing practices, and to establish long-term shifts in recycling attitudes.

1. Introduction

The management of solid waste from households has become a pressing issue in modern society. The continuous growth of urban populations and the adoption of patterns of consumption based on *throw-away culture* (Toffler, 1970) have resulted in the generation of large amounts of solid waste. Within the European Union, measures to promote the reduction, re-use, and recycling of municipal solid waste have been increasingly adopted by the European Commission, and subsequently by Member States (e.g. ED 2008/98/EC, European Council, 2008; ED 2012/19/EU European Council, 2012; or ED 2015/720/EU, European Council, 2015). Nevertheless, the amount of waste sent to landfills remains high. In 2013, about 70% of the waste generated by Spanish households was deposited onto or into the soil (60.23%) or was incinerated (9.74%) (EUROSTAT, 2015).

The problem is not only the amount of waste generated but also its characteristics. Although overall, the waste generated by households is largely considered non-hazardous, some of it does contain highly polluting elements that pose significant risks to the environment. In this work, we focus on one aspect: domestic batteries. Although batteries represent only a small percentage of the total waste generated by households, their potential for contamination is high because they could contain cadmium, (Cd), mercury (Hg), and lead (Pb), making it crucial that these wastes are efficiently collected and recycled (Bigum et al., 2013). The overarching objective of the European Directive on batteries and accumulators (ED 2006/66/EC, European Council, 2006) establishes that "Member States shall, having regard to the environmental impact of transport, take necessary measures to maximise the separate collection of waste batteries and accumulators and to minimise the disposal of batteries and accumulators as mixed municipal waste in order to achieve a high level of recycling for all waste batteries and accumulators" (Art.7, ED 2006/66/EC). In Spain, the government implemented this European Directive in the Royal Decree (RD) 106/2008 of 1 February, on batteries and accumulators and environmental management of their waste (BOE, 2008). The central mandate was to achieve the following minimum collection rates in Spain: 25% by 31 December 2011 and 45% by 31 December 2015 (Art. 15 §2, RD 106/2008). In order to achieve the proposed targets, these regulatory measures, among other actions, establish the need to design information campaigns to ensure that end-users are fully informed of "the desirability of not disposing of waste batteries and accumulators as unsorted municipal waste and of participating in

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http://dx.doi.org/10.1016/j.resconrec.2015.11.004
0921-3449/

their separate collection so as to facilitate treatment and recycling" (Art.20 §1, ED 2006/66/EC).

Several studies show that to involve households in separating and recycling different kinds of waste, information campaigns should be designed on the basis of specific and individual information (Knussen et al., 2004; Refsgaard and Magnussen, 2009; Miafozdyeva and Brandt, 2013; Zen et al., 2014). That is, to be successful, recycling campaigns should take into consideration the local conditions and cultural, situational, or demographic factors of the households addressed (Tonglet et al., 2004; Timlett and Williams, 2008; Hadjimanolis, 2013; Keramitsoglou and Tsagarakis, 2013).

Most empirical studies have found that recycling behavior among households is influenced by socio-economic variables, degree of environmental concern, level of knowledge about environmental recycling issues and social norms (Hornik et al., 1995; Hansmann et al., 2006; Hadjimanolis, 2013; Miafozdyeva and Brandt, 2013).

Of the many socio-economic variables included as independent variables in the studies on recycling, the most commonly analyzed are education, income, age, gender and different variables related to household characteristics. The results regarding influence of these variables on recycling are inconclusive. Regarding education, several works have found that higher levels of education have positive impact on recycling behavior (Hadjimanolis, 2013; Czajkowski et al., 2014; Yin et al., 2014). However, there are also a similar number of studies founding no such significant relation between education and recycling (Sidique et al., 2010; Rioux, 2011; Wang et al., 2011; Pearson et al., 2012). Age is the most frequently analyzed socio-economic variable (Miafozdyeva and Brandt, 2013). Several authors report a significant and positive correlation between age and recycling behavior (Hage et al., 2009; Sidique et al., 2010; Hadjimanolis, 2013; Keramitsoglou and Tsagarakis, 2013). However, there are also studies showing a negative relationship between these two variables (Czajkowski et al., 2014). Furthermore, other studies have not found a significant correlation between them (Barr et al., 2001; Rioux, 2011). Another usually analyzed variable is income. Most studies found that income and recycling have a significant correlation (Nnorom et al., 2009; Gellynck et al., 2011; Hadjimanolis, 2013; Czajkowski et al., 2014; Zen et al., 2014; Babaei et al., 2015), whilst some few works have reported no correlation (Hansmann et al., 2006; Hage et al., 2009; Rioux, 2011; Pearson et al., 2012). However, this correlation is ambiguous. Several works indicate that households with higher income recycle more than households with lower incomes (Nnorom et al., 2009; Czajkowski et al., 2014; Zen et al., 2014). In contrast, other works show that households with higher income not necessarily have a rate of recycling higher than other households (Hage and Söderholm, 2008; Gellynck et al., 2011). Regarding gender, some studies consider that this variable has not a relevant influence on recycling behavior (Hansmann et al., 2006; Hage et al., 2009; Sidique et al., 2010). Nevertheless, several works have found evidence that women are more likely to recycle than men (Chung and Poon, 1996; Pearson et al., 2012; Hadjimanolis, 2013; Babaei et al., 2015). Among household characteristics included in previous research, we can note, household size (Tadesse, 2009; Wan et al., 2014), marital status (Sidique et al., 2010; Pearson et al., 2012), or the type of house (Hage et al., 2009; Sidique et al., 2010; Zen et al., 2014), among others.

Moreover, the literature contains references to other socio-economic variables. For example, with the increase in migration processes, studies including the origin of the individuals have become more common (Hage et al., 2009; Pearson et al., 2012; Zen et al., 2014). The relationship with the economic activity is also analyzed recently in some works (Omran et al., 2009; Babaei et al., 2015; Nguyen et al., 2015).

The analysis of influence of knowledge of environmental issues on recycling is very usual in the empirical studies. It is well documented that environmental concern affects recycling behavior positively (Hornik et al., 1995; Hage and Söderholm, 2008; Hage et al., 2009; Nnorom et al., 2009; Refsgaard and Magnussen, 2009; Tadesse, 2009; Best and Kneip, 2011). Most of studies that include this variable conclude that environmental concern has a positive correlation with recycling behavior. Other studies, however have shown that no significant relationship or a very weak relationship between this variable and recycling behavior (Barr et al., 2001; Tonglet et al., 2004; Wang et al., 2011).

Similarly, several researchers found a direct link between the recycling behavior of households and their knowledge about specific recycling issues (Hansmann et al., 2006; Sidique et al., 2010; Hadjimanolis, 2013; Keramitsoglou and Tsagarakis, 2013; Nguyen et al., 2015).

It is well documented that social norms have a substantial influence on recycling behavior of a person. The social norms are often defined as norms that the individual perceives to be hold by significant others who are important for he or she (Hansmann et al., 2006; Miafozdyeva and Brandt, 2013). In this context, several works conclude that person's interest to show a social desirable behavior (i.e. a pro-environmental behavior) is positively linked to recycling behavior (Hornik et al., 1995; Chu and Chiu, 2003; Sidique et al., 2010; Rioux, 2011; Videras et al., 2012; Czajkowski et al., 2014; Wan et al., 2014; Zen et al., 2014; Nguyen et al., 2015). In contrast, some few studies report that social norms have not relevant influence on recycling (Chan, 1998; Knussen et al., 2004; Hage et al., 2009).

As we have seen, the relative influence of analyzed variables on recycling behavior varies greatly in the literature. This is due to these studies has been carried out in different countries by researchers of different disciplines (economics, psychology, engineering, etc.) that address different concerns (Hornik et al., 1995; Miafozdyeva and Brandt, 2013). Furthermore, it should be pointed out that prior empirical works focus on general issues of recycling behavior, considering the solid waste from households as a homogeneous whole (Barr et al., 2001; Gellynck et al., 2011; Miafozdyeva and Brandt, 2013; Czajkowski et al., 2014; Zen et al., 2014). Nevertheless, since domestic solid waste is heterogeneous, an individualized analysis of factors that influence behavior toward recycling specific waste containing potentially hazardous materials, such as batteries, can be very useful in designing the most effective educational and information campaigns to improve the percentages of correct disposal. This is an issue that only a few recent studies have tried to analyze (Hansmann et al., 2006; Nnorom et al., 2009; Wang et al., 2011; Yin et al., 2014).

In this context, the purpose of this paper is to identify the important decision-drivers that affect the recycling efforts of Spanish individuals through the separate collection of batteries. Specifically, we want to answer the following questions:

- What factors influence the decision to deposit used batteries into collection points?
- Which factors are the most influential in this decision?

To this end, we carry out an empirical study estimating a bivariate probit model where the dependent variable is the household attitude to recycling batteries, which we explain through a set of attitudinal (environmental concern, awareness of some environmental problem and knowledge of environmental campaigns) and socio-economic (age, education level, type of household, etc.) factors. Studies which deal with recycling issues using binary models can be found in the literature. Most of them estimate a one-equation model, using logistic regressions, ordered probit and multinomial logit models (Hage et al., 2009; Nnorom et al., 2009; Wang et al., 2011; Czajkowski et al., 2014). Only some of them estimate a multi-equation model, for example Tadesse (2009) estimates a bivariate probit model, together a bias selection model.

The paper is organized as follows. Section 2 is devoted to explain the most relevant issues of our empirical analysis: the data, the variables and the econometric methodology. The empirical analysis carried out and the results obtained are in Section 3. Section 4 closes the paper with some final considerations.

2. Method

This section describes the sources and data used for carrying out the empirical study. Also reports the definition of the variables of interest. Finally, this section includes the specific econometric methodology that we have applied in this study.

2.1. The data

The information used in this analysis comes from the "Survey on Households and the Environment 2008" conducted by The Spanish Statistical Institute (INE), on a sample of more than 20,000 Spanish households, with the aim "to study the habits, consumption patterns and attitudes of households as regards the environment" (INE, 2009; p. 3). The interview method used, in general, was the personal interview, although the possibility of providing the information online was also offered, or even on a free telephone number (INE, 2009; ch. 8).

To ascertain the environmental awareness of individuals, they were asked the following questions:

- Are you concerned about the environment?
- Have you detected any environmental problem in your surroundings during the previous year?
- Have you had knowledge of any environmental protection awareness campaign in the last year?

Regarding recycling attitudes, individuals were asked about the sorting and deposit (or failure to deposit), at a specific collection point (green points, drop-off system at central points of town, collection containers, etc.), of a set of wastes, among which were batteries.

The survey also includes information on the characteristics of individuals (income, age, working status, gender, education level, etc.) and the size of the city of residence.

2.2. Variable specification

The variables considered in the empirical study are summarized in Table 1.

As we can see, the dependent variable we are interested is a binary variable labeled *Recycle*, which takes value 1 if the respondent dispose of batteries separately, and 0 otherwise. We consider the following set of explanatory factors:

- Concern about the environment (*Concern_envir*). This is the main factor whose influence on the decision to recycle we want to analyze. We define it as a dummy variable which takes value 1 if the individual responds affirmatively to the survey question related to "concern about environment" and 0 otherwise.
- Age of respondent (*Age*).
- Net monthly income of the household of the respondent. This variable counts the sum of the average regular income received by all household members of the respondent, as the average of the last 12 months, after taxes and social security contributions. Following INE (2009), three brackets of monthly income are initially considered to analyze whether recycling behavior differs across individuals with different net incomes: high income (more than €2700), medium income (€1101–€2700) and low income (less than €1100).
- Country of birth of the respondent (*Spain_birth*).
- Type of household (*Couple_child*). This variable takes into account whether the individual is living in couple with children or in another type of household (alone, couple without children . . .).
- The education level. This factor refers to the highest level of studies completed by the respondent. Following INE (2009), we have three levels: basic (includes those without studies or with primary education or equivalent, or with the first stage of secondary education), medium (includes those with the second stage of secondary education or professional training or equivalent) and high (includes those with university studies). The corresponding dummy variables are given by:
- Relationship with economic activity. Following INE (2009), the respondent is classified as employed, unemployed, student, retired, or other.
- The size of the city where the individual lives. This variable is used to identify possible differences in recycling attitudes due to city size. According to information about intervals provided by INE (2009), the breakdown used to define this factor is: large cities (provincial capitals and cities with more than 100,000 inhabitants), medium-sized cities (20,000–100,000 inhabitants) and small cities (fewer than 20,000 inhabitants).
- Gender of respondent (*Man*). It is a dummy variable that takes value 1 for men, and value 0 for women.
- Knowledge about an environmental awareness campaign (*Camp*). We take into account whether or not the person had knowledge of any environmental awareness campaign (water, recycling . . .) in the last year.

Table 1
Definition of variables.

Dependent variable: *Recycle* (collect separately batteries = 1, otherwise = 0)	
Explicative variables	Definition
Concern_envir	Concern about the environment (yes = 1, no = 0)
Age	Age of respondent
Hinc	High income (net monthly income more than €2700 = 1, otherwise = 0)
Minc	Medium income (net monthly income between €1101 and €2700 = 1, otherwise = 0)
Linc	Low income (net monthly less than €1101, otherwise = 0)
Spain_birth	Country of birth of the respondent (birth in Spain = 1; 0 = otherwise)
Couple_child	Type of household (living in couple with children = 1, otherwise = 0)
Bedu	Basic education level (yes = 1; no = 0)
Medu	Medium education level (yes = 1; no = 0)
Hedu	High education level (yes = 1; no = 0)
Employ	Employed (yes = 1; no = 0)
Unemploy	Unemployed (yes = 1; no = 0)
Retired	Retired (yes = 1; no = 0)
Student	Student (yes = 1; no = 0)
Lcitsize	Large city (provincial capitals and cities with more than 100,000 inhabitants = 1, otherwise = 0)
Mcitsize	Medium-sized city (cities with 20,000–100,000 inhabitants)
Scitsize	Small cities (cities with fewer than 20,000 inhabitants = 1, otherwise = 0)
Man	Gender variable (man = 1; woman = 0)
Camp	Knowledge about an environmental awareness campaign (yes = 1; no = 0)
Detect	Detection of environmental problems (the individual knows of an environmental problem in his/her surroundings in the last year 0, otherwise = 0)

- Detection of environmental problems (*Detect*). A factor that can affect recycling decisions is awareness of some environmental problem in their surroundings.

2.3. The econometric methodology

As we have previously mentioned, our dependent variable (*Recycle*) is binary, representing the decision of the individuals about disposing of used batteries separately. Thus, we must specify a "binary choice model", being the most used probit and logit models. Next, we summarize the general aspects of these models, to make understandable the specific model estimated in this study.

Specifically, if Y_1 is a binary variable (*Recycle*), the model can be expressed as:

$$Y_1 = 1[\mathbf{z}_1\boldsymbol{\delta}_1 + u_1 > 0] \tag{1}$$

This expression combines the binary variable and the latent model which underlies it that can be written as:

$$Y_1^* = \mathbf{z}_1\boldsymbol{\delta}_1 + u_1$$

where Y_1^* is a latent variable representing a satisfaction or utility of the decision-maker, which allows the individuals to choose one of the two options (quantified by 1 and 0), obtaining the Y_1 variable. That is:

$$Y_1 = \begin{cases} 1 & \text{if } Y_1^* > 0 \\ 0 & \text{if } Y_1^* \leq 0 \end{cases}$$

Moreover, $\mathbf{z}_1$ is the vector of the regressors which explain Y_1, $\boldsymbol{\delta}_1$ is the parameter vector, and u_1 the error term of the model.

The usual way of writing these binary models is:

$$P = F(\mathbf{z}_1\boldsymbol{\delta}_1) \tag{2}$$

with F the cumulative distribution function of the error term u_1 of (1), and P is a probability, $P = \mathrm{pr}(Y_1 = 1)$. If u_1 is N(0,1) we have the probit model $P = \Phi(\mathbf{z}_1\boldsymbol{\delta}_1)$, while if u_1 is logistic, the model is logit $P = \Lambda(\mathbf{z}_1\boldsymbol{\delta}_1)$.

If we assume a probit model, the log-likelihood we have to minimize to get the probit maximum likelihood estimates (ML) is:

$$\ell(Y, \boldsymbol{\delta}_1 | \mathbf{z}_1) = \sum_{i=1}^{N} [Y_i \log \Phi(\mathbf{z}_{1i}\boldsymbol{\delta}_1) + (1 - Y_i)\log(1 - \Phi(\mathbf{z}_{1i}\boldsymbol{\delta}_1))]$$

These estimates will be consistent if all factors included in the $\mathbf{z}_1$ vector are exogenous. We must consider that every estimated parameter cannot be directly interpreted as a change in the probability of choose the option quantified by $Y_1 = 1$. The change in probability under a unit change in a given regressor of $\mathbf{z}_1$, z_{1j}, is obtained as a derivative $\partial P/\partial z_{1j}$ if the regressor is continuous, and as an increment $\Delta P/\Delta z_{1j}$ if the explanatory variable is discrete.

Nevertheless, our case is more complicated, because one of the binary explanatory factors could be endogenous. Specifically, we consider a variable Y_2 (*Concern_envir*), which takes value 1 if the individual has concern for the environment, and 0 otherwise. Then, instead of (1), the equation would be:

$$Y_1 = 1[\mathbf{z}_1\boldsymbol{\delta}_1 + \alpha_1 Y_2 + u_1 > 0] \tag{3}$$

If Y_2 is endogenous, the probit estimation of this model provides inconsistent estimates. This is the reason which justifies the use of a bivariate probit model, written as follows:

$$Y_1 = 1[\mathbf{z}_1\boldsymbol{\delta}_1 + \alpha_1 Y_2 + u_1 > 0] \tag{4}$$

$$Y_2 = 1[\mathbf{z}\boldsymbol{\delta}_2 + v_2 > 0] \tag{5}$$

If Y_2 is endogenous, it will depend on other explanatory factors, included in the $\mathbf{z}$ vector.

We here follow the notation and the procedure presented by Wooldridge (2002, p. 477). The vector $\mathbf{z}$ must include some variables that does not belong to $\mathbf{z}_1$; (u_1, v_2) are error terms assumed to be independent of $\mathbf{z}$ and bivariate normal distributed, with mean zero, each with unit variance and $\rho_1 = Corr(u_1, v_2)$.

We focus on the Y_1 variable, that is, on the estimation of Eq. (4), in order to get the estimated probability of recycle. If $\rho_1 \neq 0$, then u_1 and v_2 are correlated, Y_2 is an endogenous variable, and probit estimation of Eq. (4) is inconsistent for $\boldsymbol{\delta}_1$ and α_1, as we have previously mentioned about model (3). To estimate consistently, we must take into account Eq. (5), and derive the corresponding likelihood function (see Appendix A).

Once the maximum likelihood estimation is obtained, we can test for exogeneity of Y_2 by using the score test of $H_0: \rho_1 = 0$. If H_0 is not rejected we can estimate just a probit for Eq. (1) obtaining consistent estimators. If H_0 is rejected, we have to estimate the two-equation system by ML.

3. Results of the study

This section presents the results of the estimation of the two-equation model (4) and (5) explained in Section 2, where binary variables Y_1 and Y_2 correspond to *Recycle* and *Concern_envir*, respectively. Remember that our interest is focused on the probability of recycling, that is, $P(Recycle = 1) = P(Y_1 = 1)$. The variables that finally are included in vectors $\mathbf{z}$ and $\mathbf{z_1}$ can be seen in Table 2. We previously carried out a preliminary estimation that allowed us to reduce the number of dummy variables, grouping the qualitative factors into fewer categories. In particular, there are non-significant differences between medium and high education levels. Similarly, medium-sized and small-sized cities are grouped, and also *Unemployed* and "other categories".

As we noted in Section 2, if Y_2 (*Concern_envir*) is endogenous, we cannot estimate (4) as a one-equation probit. Therefore, the two-equation model (4) and (5) should be estimated by ML. However, if Y_2 is an exogenous factor in Eq. (4), this equation should be estimated by probit ML. Then, it is evident that, before estimating, we must know if Y_2 is endogenous or exogenous. With this aim, we use the score test for testing $H_0: \rho_1 = 0$, which is distributed as a χ^2_1. Table 3 shows the result of this test. The statistic value is 10.293,

Table 2
Variables included in vectors $\mathbf{z}$ and $\mathbf{z}_1$.

Vector $\mathbf{z}$	Vector $\mathbf{z}_1$
Concern_envir	*Couple_child*
Couple_child	*Linc*
Linc	*Spain_birth*
Hinc	*Bedu*
Spain_birth	*Hedu*
Employ	*Lcitsize*
Student	*Age*
Retired	*Age*^{2}
Bedu	*Camp*
Lcitsize	*Detect*
Age	*Man*
Age^2	
Camp	
Detect	

Table 3
Test of exogeneity.

Test of exogeneity for *Concern_envir*	
Hypotheses	$H_0: \rho_1 = 0$; $H_A: \rho_1 \neq 0$
$\hat{\rho}_1$	−0.363
Statistic value	10.293
Distribution	χ^2_1
p-Value	0.0013

Table 4
Estimated probit model for *Recycle* with a binary endogenous variable.

Regressors ($\mathbf{z}_1$)	Coefficient	SD	*t*-Ratio	*p*-Value
Equation (4). Dependent variable: *Recycle*				
const	−0.971	0.106	−9.174	4.54e−020
Concern_envir	1.018	0.146	6.989	2.77e−0.12
Couple_child	0.079	0.023	3.451	0.0006
Linc	−0.291	0.026	−11.31	1.13e−029
Hinc	0.114	0.035	3.219	0.0013
Spain_birth	0.375	0.04	9.356	8.32e−021
Employ	0.07	0.028	2.475	0.0133
Student	0.402	0.068	5.873	4.28e−09
Retired	0.074	0.031	2.370	0.0178
Bedu	−0.242	0.026	−9.150	5.69e−020
Lcitsize	0.112	0.022	5.153	2.57e−07
Age	0.018	0.004	4.325	1.53e−05
Age^2	−0.0001	4.005e−05	−3.635	0.0003
Camp	0.132	0.032	4.063	4.84e−05
Detect	−0.054	0.027	−2.009	0.0446
Equation (5). Dependent variable: *Concern_envir*				
const	−0.608	0.087	−6.981	2.94e−012
Linc	−0.067	0.026	−2.607	0.009
Bedu	−0.159	0.028	−5.682	1.33e−08
Lcitsize	0.076	0.023	3.386	0.0007
Man	−0.129	0.021	−6.125	9.05e−010
Age	0.047	0.003	14.86	5.62e−050
Age^2	−0.0005	2.993e−05	−15.68	1.96e−055
Couple_child	0.046	0.024	1.92	0.055
Spain_birth	0.141	0.041	3.4	0.0007
Hedu	0.105	0.037	2.807	0.005
Camp	0.495	0.022	22.25	1.03e−109
Detect	0.399	0.028	14.28	3.11e−046

and the *p*-value shows that the null hypothesis is clearly rejected, meaning that the factor *Concern_envir* is endogenous in the first Eq. (4), so the estimation by ML of the system (4) and (5) is adequate.

Table 4 includes the ML estimation of the parameters of Eqs. (4) and (5). As we commented in Section 2, these parameters do not have their own interpretation, but they do provide the sign of the change in probability under changes in regressors. Thus, the marginal effects must be calculated to obtain the magnitude of this change in probability. To separate both aspects, we divide this section into two parts: firstly the estimated parameters are commented and afterwards, the analysis of the marginal effects is carried out. This analysis is very important, in order to answer the questions raised in Section 1.

3.1. The estimated parameters

First we focus on the part of Table 4 corresponding to Eq. (4). The factors which are in this equation have a direct effect on the recycling probability of batteries. As we can see the coefficient of *Concern_envir* variable is positive. This result agrees with previous findings that people who show an environmental concern will recycle more (Tadesse, 2009; Nnorom et al., 2009; Best and Kneip, 2011).

The negative sign of the parameter corresponding to the variable *Linc* indicates that people with low incomes have a lower recycling probability. This negative relationship is consistent with previous findings by Czajkowski et al. (2014) and Zen et al. (2014). Likewise, the negative sign of *Bedu* shows that individuals with basic education have a lower probability of recycling than those with medium or high education. Hadjimanolis (2013) and Czajkowski et al. (2014) report similar result. Similarly, we find that the fact of having detected an environmental problem in the last year does not increase the probability of recycling (negative sign of *Detect* variable). This could be because environmental problems detected by most individuals are not related to batteries disposal.

The sign of coefficient for *Age* (positive) is in line with previous works (Sidique et al., 2010; Hadjimanolis, 2013). Furthermore, the negative sign of Age^2 shows interesting results, allowing us to conclude that an increase of a year in age implies an increase in the probability of recycling, but this increase becomes smaller as the individual gets older.

The estimated parameters of the remaining variables (*Couple_child*, *Spain_birth*, *Hinc*, *Camp*, *Employ*, *Student*, *Retired* and *Lcitsize*) have a positive sign. Therefore individuals living in couple with children have a higher probability of recycling than those living in other types of household. This result is in line with previous works (Sidique et al., 2010). The probability of recycling is also higher for individuals born in Spain. This result conforms to the findings of earlier works that indicate origin of the individuals is a significant factor motivating recycling behavior (Hage et al., 2009; Pearson et al., 2012; Zen et al., 2014). Furthermore, those who live in a household with a high level of income tend to recycle more than those who live in households with medium and low levels of income. This result is consistent with both previous coefficient obtained for *Linc* and previous studies (Czajkowski et al., 2014; Zen et al., 2014). Analogously, individuals who are employed, retired, and students have higher probability than those belonging to other activity category. The positive relation between employ and recycling outcomes is similar to previously studies of Omran et al. (2009) and Babaei et al. (2015). Additionally, the results obtained for *Student* and *Retired* agree with the estimated parameter obtained for *Age* (Hage et al., 2009; Hadjimanolis, 2013). The finding that people living in a large city have a higher probability of recycling than people living in medium and small cities contradicts partly the previous study of Pearson et al. (2012), but it supports previous findings about that easy availability of recycling facilities has an important positive effect on recycling efforts (Hage et al., 2009; Keramitsoglou and Tsagarakis, 2013; Zen et al., 2014). In Spain, specific waste containers for batteries are more common in large cities, so the time and effort needed to a correct disposal is lower in these cities than in medium and small cities. Finally, having knowledge of an environmental awareness campaign in the previous year increases the probability of recycling. Ramayah et al. (2012) reported that public campaigns were effective in encouraging recycling behavior.

The second part of Table 4 shows the estimated parameter values of Eq. (5). The regressors of this equation explain, in a direct way, the binary variable *Concern_environ*; in other words, these regressors have a direct effect on the probability of having environmental concern. Moreover, given that *Concern_environ* is a regressor of Eq. (4), we can affirm that regressors in $\mathbf{z}$ have also an indirect effect on the recycling probability. Then, those factors that are in both Eqs. (4) and (5), have direct and indirect effects on the recycling probability. Specifically, gender (*Man*) and high education (*Hedu*) have only indirect effects, while *Camp*, *Detect*, *Age*, Age^2, *Prim*, *Linc* and *Lcitsize* have both direct and indirect effects. Finally, there are a group of factors that only have direct effects, including having high income (*Hinc*), and the relationship with economic activity (*Employ*, *Student*, *Retired*).

3.2. The marginal effects of the regressors

As we have indicated, we can extract some conclusions from the sign of the estimated parameters, but these parameters do not give the marginal effects that show the change in the corresponding probability due to changes in the explanatory factors. Our main aim is to calculate the marginal effects in the probability of recycle ($P(Y_1 = 1)$), so we now describe the way we obtain such effects.

We distinguish the effect of continuous explanatory variables from that of discrete regressors; the way of calculating the effects is different. Even in every one of these two categories (continuous/discrete) we must work differently depending on the situation. We now analyze every case.

3.2.1. Continuous regressors

As we explained in Section 2, the change in recycling probability under changes in a continuous explanatory factor is obtained by calculating the derivative, that is, $\partial\hat{P}/\partial z_{1j}$. The only continuous regressors in our study corresponds to the age, which is included twice, *Age* and *Age*^{2}. Then, the marginal effect is obtained as:

$$\frac{\partial\hat{P}}{\partial Age} = (\hat{\delta}_{Age} + 2\hat{\delta}_{Age^2}Age)\phi(\mathbf{z}_1\hat{\boldsymbol{\delta}}_1 + \hat{\alpha}_1 Y_2) \quad (8)$$

with $\hat{\delta}_{Age}$ and $\hat{\delta}_{Age^2}$ being the parameters of $\boldsymbol{\delta}$ which corresponds to *Age* and *Age*^{2}, and $\phi(\cdot)$ the normal density function.

The average of (8) for all observations provides a measure of the change in probability due to an increase of 1 year in age. This average value is 0.00084, so we can see that, on average, the influence of age is low.

Moreover, from expression (8) and given the value of the estimated parameters $\hat{\delta}_{Age} = 0.0181388$ and $\hat{\delta}_{Age^2} = -0.000145581$, we find that if age increases by one year, the probability of recycling increases, but more slowly until the age of 62. From 63 years old, an additional year reduces the probability of recycling.

3.2.2. Discrete regressors

Given our specific model, we must also distinguish between endogenous and exogenous discrete regressors, because the corresponding marginal effect is obtained differently.

3.2.2.1. Endogenous binary regressor. The variable *Concern_environ* is endogenous, so the estimation of model (4) and (5) provides, for every observation, the probabilities of recycling conditioned to the values of *Concern_environ*, that is, $P(Y_1 = 1 \,|\, Y_2 = 1)$ and $P(Y_1 = 1 \,|\, Y_2 = 0)$. The difference in the probability of recycling between those who have environmental awareness and those who do not takes, on average for all households, a value of 0.3807; the way of obtaining such value is:

$$\frac{\Delta P(Recycle)}{\Delta Concern\_environ} = \bar{P}(Y_1 = 1 \,|\, Y_2 = 1) - \bar{P}(Y_1 = 1 \,|\, Y_2 = 0) \quad (9)$$

with $\bar{P}$ indicating the average probability for all observation.

3.2.2.2. Exogenous binary regressors. For this kind of regressors, the way of calculating changes in probability differs from the previous case, and it is the same way as in a one-equation probit model. For example, the change in probability of recycling between those who live in couple with children, and those living in another family situation is obtained as follows:

$$\Delta\hat{P} = \Phi\left(\mathbf{z}_1^{\bullet}\hat{\boldsymbol{\delta}}_2^{\bullet} + \hat{\gamma}Y_2 + \hat{\delta}_{Couple\_child}\right) - \Phi\left(\mathbf{z}_1^{\bullet}\hat{\boldsymbol{\delta}}_2^{\bullet} + \hat{\gamma}Y_2\right) \quad (10)$$

with $\mathbf{z}_1^{\bullet}$ being the vector $\mathbf{z}_1$ except *Couple_child*, and $\boldsymbol{\delta}_2^{\bullet}$ being the vector $\boldsymbol{\delta}_2$ except *Couple_child*. This is the procedure for every explanatory factor; note that, if the factor has more than two categories, e.g. income, we must compare pairs of probabilities. The average for all observations gives the corresponding measure of the change in probability. These marginal effects of binary exogenous regressor can be understood as differences in probability of recycling between groups. For example, expression (10) measures the difference between the group of people living in couple with children and the group of persons who live in other relationships. For variables representing income (*Hinc* and *Linc*), we will compare the group of high income (*Hinc* = 1 and *Linc* = 0) with medium income (*Hinc* = 0 and *Linc* = 0), low (*Hinc* = 0 and *Linc* = 1) with medium income (*Hinc* = 0 and *Linc* = 0), and high(*Hinc* = 1 and *Linc* = 0) with low income (*Hinc* = 0 and *Linc* = 1). These "differences in probability of recycling" are presented, for all binary exogenous regressors, in Table 5.

Table 5
Marginal effects of the exogenous binary regressors.

The compared groups: Group 1 vs. Group 2		Average difference in probability of recycling
Group 1	Group 2	Pr (Group 1) – Pr (Group 2)
Couple with children	Other situation	0.022
High income	Medium income	0.030
Low income	Medium income	−0.087
High income	Low income	0.118
Spanish birth	Non-Spanish birth	0.116
Employed	Student	−0.085
Employed	Retired	0.0001
Employed	Other situation	0.020
Student	Retired	0.084
Student	Other situation	0.106
Retired	Other situation	0.021
Basic education level	Medium-high education level	−0.069
Large town	Medium-small city	0.032
Detecting envir. problem	Non-detecting envir. problem	−0.0155
Envir. campaign	Non-envir. campaign	0.038

In Table 5, we can see that there are three pairs of groups with large differences in probability of recycling: (i) Those who are born in Spain have a probability of recycling 0.116 higher than those born in other countries; (ii) Having high income increases the probability by 0.118, with respect to individuals of low income; (iii) The probability of recycling for students is 0.106 higher than that of those in "other situation" (unemployed, . . .). Other pairs of groups have lesser differences. Couples with children have a probability a little higher than those living in a different type of household. This probability is also slightly greater for individuals with awareness of an environmental campaign during the previous year. Additionally, the recycling probability increases slightly for those who live in a large town compared to those living in small- and medium-sized cities, and for individuals who have a high or medium education level, compared to those with basic education. Finally, detecting an environmental problem in his/her surroundings during the previous year does not seem to affect the probability of recycling.

We now analyze specifically the qualitative factors with more than two categories, in order to determine if there are important differences between the groups. Then, paying attention to the economic activity of the individuals (employed, retired, students, and other situation), we observe that students have the highest probability, whichever other category we use for comparison. At the same time, there are small differences in probability of recycling between the other groups of activity. With regard to income levels, we see that those with higher incomes have a higher probability to recycle than those with low income. Linked to this result, we find that there is an important difference in this probability between the lower and middle incomes. However, there is almost no difference between high and middle incomes.

In spite of these results, we want to remark that the differences in recycling probability collected in Table 5 are much smaller than those corresponding to the variable *Concern_envir* that, as we have previously calculated, has a value of 0.38, reflecting the importance of this endogenous regressor.

4. Final considerations

Due to their hazardous components, batteries for domestic use may generate several environmental problems. Despite that, in recent decades, the EU has drafted a broad range of measures to improve the separate collection of this particular waste, little research has empirically analyzed the drivers of household participation in the separate collection of batteries.

The aim of this paper is to analyze the factors influencing the decision of Spanish individuals to deposit their used batteries into collection points. To this end, we define a binary variable *Recycle*, representing individual decisions on this question. A probit model is specified, and its estimation requires a previous test of exogeneity for the factor "concern about the environment", due to its possible endogeneity. Given that the result of the test confirms that this factor is endogenous, a bivariate probit model is estimated, providing a convenient estimation of the effect of the endogenous binary regressor (concern about the environment) on the binary variable *Recycle*.

From the model estimation we can answer the two questions initially purposed: What factors influence the decision to deposit used batteries into collection points? and Which factors are the most influential in this decision?

- An important finding is that the respondent's concern about the environment is a very significant factor influencing the recycling of batteries.
- The respondent's knowledge of an environmental awareness campaign positively affects recycling attitudes.
- Another important result of this study is that a set of socio-economic variables, such as age, country of birth, the relationship to economic activity, income, and education level, which likely have a great influence on consumption patterns (and hence waste generation), affects recycling attitudes directly, and indirectly by way of environmental concerns.
- Especially relevant is the finding that arises from the *Age* variable. As we have indicated, the probability of recycling batteries increases with age, but this increase becomes smaller over time, up to the age of 62. From then on, the probability decreases, indicating that individuals will adopt recycling-specific attitudes more readily when young, but in later years they are less receptive to changing their behavior.
- The size of the city was found to have a significant, though quite small, effect on the probability of recycling this particular form of waste.

In conclusion, environmental education (from primary school to university) plays an important role in improving future recycling practices in general, and to promoting the separate collection of batteries, in particular. Thus, it is very important to support communication and education programs that reinforce the environmental knowledge of individuals. With an improvement in environmental awareness, it may be possible to encourage more individual participation in battery and accumulator recycling programs, and especially in the separate collection of this domestic hazardous waste.

The results obtained help us to discern a profile of individuals according to their interest in recycling batteries. These results would be useful in designing measures based on the characteristics of individuals in order to involve them in the separate collection of this waste. Adopting specific measures will help to improve existing practices, and to establish long-term shifts in recycling attitudes.

Finally, we should note that his study has two limitations that should be addressed in future research:

- The empirical analysis has been carried out using cross-sectional data. Because past situations can influence future decisions and lags in adopting measures can be relevant in recycling behavior, future research using time series data set could be of interest to analyze recycling intentions.
- The study is focused on reality of a developed country in Europe, Spain. As such, our findings could not be generalized in other areas and contexts. Therefore, further research could be developed applying bivariate probit models in other countries.

Acknowledgements

This research was supported by the Industry and Innovation Department of the Government of Aragon (Spain) and the European Social Fund (consolidated research groups S-19 and S-21).

Appendix A. Log-likelihood function of Eq. (5)

The joint distribution of (Y_1, Y_2) given $\mathbf{z}$ is $f(Y_1, Y_2|\mathbf{z}) = f(Y_1|Y_2, \mathbf{z})f(Y_2|\mathbf{z})$.

To construct the log-likelihood, we combine the four possible outcomes of (Y_1, Y_2):

$$P(Y_1 = 1|Y_2 = 1, \mathbf{z}) = \frac{1}{\Phi(\mathbf{z}\boldsymbol{\delta}_2)} \int_{-\mathbf{z}\boldsymbol{\delta}}^{\infty} \Phi\left[\frac{\mathbf{z}_1\boldsymbol{\delta}_1 + \alpha_1 Y_2 + \rho_1 v_2}{(1-\rho_1{}^2)^{1/2}}\right] \phi(v_2)\,dv_2 \tag{A.1}$$

$$P(Y_1 = 1|Y_2 = 0, \mathbf{z}) = \frac{1}{1-\Phi(\mathbf{z}\boldsymbol{\delta}_2)} \int_{-\mathbf{z}\boldsymbol{\delta}}^{\infty} \left[\Phi\frac{\mathbf{z}_1\boldsymbol{\delta}_1 + \alpha_1 Y_2 + \rho_1 v_2}{(1-\rho_1{}^2)^{1/2}}\right] \phi(v_2)\,dv_2 \tag{A.2}$$

Of course, $P(Y_1 = 0|Y_2 = 1, \mathbf{z})$ and $P(Y_1 = 0|Y_2 = 0, \mathbf{z})$ are just one minus expression (A.1) and one minus expression (A.2) respectively. Taking the log we obtain the log-likelihood function for maximum likelihood (ML) analysis. As argues Wooldridge (2002), we could think that a two-step procedure could be adequate. In this sense, since $E(Y_2|\mathbf{z}) = \Phi(\mathbf{z}\boldsymbol{\delta}_2)$ and $\boldsymbol{\delta}_2$ is consistently estimated $(\hat{\boldsymbol{\delta}}_2)$ by probit of Y_2 on $\mathbf{z}$, it is tempting to estimate $\boldsymbol{\delta}_1$ and α_1 by probit of Y_1 on $\mathbf{z}_1$ and $\hat{\boldsymbol{\Phi}}_2$, where $\hat{\Phi}_2 \equiv \Phi(\mathbf{z}\boldsymbol{\delta}_2)$. This method does not produce consistent estimates, so we must estimate by the ML method that we proposed.

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