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Dipartimento Economia e Statistica Cognetti de Martiis

Working Paper Series

09/21

THE ROLE OF ENVIRONMENTAL AND FINANCIAL CONCERNS ON ENERGY-SAVING INVESTMENTS: A STOCHASTIC DOMINANCE ANALYSIS

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The Role of Environmental and Financial Concerns on Energy-Saving Investments: A Stochastic Dominance Analysis

March 2021

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Abstract

In this paper we investigate whether households' environmental and financial concerns have any effect on their energy-saving investments. Exploiting a comprehensive dataset covering thirty European countries we investigate if financially concerned and environmentally minded households feature different adoption paths. The results show that environmental and financial concerns play an important role in the decision of adopting energy saving technologies, thus paving the way for policy actions targeted at enhancing consumer awareness. Our analysis also revealed that environmentally and financially concerned households exhibit different socio-economic profiles. We find that environmentally minded, highly educated households living in urban areas with large family size are more likely to adopt than their counterparts with low level of education living in rural areas. On the other side, income is an important factor explaining adoption of economically concerned household. From the methodological point of view our analysis is based on both parametric and non-parametric methods. Namely, we use stochastic dominance analysis to rank distribution functions of household behaviour and the logit model to investigate the socio-economic profile of different groups.

Keywords: energy efficient technologies, adoption, environmental and financial attitudes, stochastic dominance

***JEL* classification:** Q40, Q55, D1

1. Introduction

A puzzle of central relevance to energy and climate policy is why in the private residential sector there are still untapped opportunities to reduce energy costs through increased energy efficiency. The economic literature has thoroughly investigated the causes of such under-investment providing a large and variegated body of theory and evidence on the barriers on the adoption of energy efficient technologies (see for example, Jaffe and Stavins, 1994; Jaffe, Newell and Stavins, 2002*).* A growing body of scientific research demonstrates that consumer choices and actions often deviate from the rational choice models which postulates that economic actors objectively weighs up the costs and benefits of all alternatives before choosing the optimal course of action (see Kollmuss and Agyeman, 2002). One domain of consumer behaviour where this gap is evident is residential energy use (see for example Flynn et al. 2010). Kollmuss and Agyeman (2002) refer to this as attitude-action gap to indicate a situation where there is a misalignment between consumer attitude and consumer practical steps to reduce household energy consumption. The authors suggest that in many cases individuals' awareness about environmental problems does not translate into pro-environmental choices.

Against this background, in this paper we contribute to the debate by examining the role of environmental and financial concerns on adoption of energy saving technologies. Exploiting data from the *Second consumer market study on the functioning of the retail electricity markets for consumers in the EU* (2017) that covers thirty European countries, we investigate if households' environmental and financial concerns have an impact on adoption of energy saving technologies. Questions we are trying to answer in this work are the following: Do financially and environmentally concerned household show different patterns of adoption? A closely related question is: Does a statement of being environmentally minded or financially constrained actually induces individuals and households to engage in adoption of energy saving technology? In other words, does awareness translates to action? Moreover, there is substantial evidence that households' decisions to invest in energy saving technology heavily depend on socio-economic factors (see Urban et al., 2012; Trotta, 2018; Schleich, 2019 among others). Accordingly, a second objective of this paper is to investigate if socio-economic determinants of adoption are different for financially and environmentally minded households. To account for financial constraints in the household decision making process, we consider three energy saving technologies of increasing cost. Namely, low cost low-energy bulbs, middle cost energy-efficiency-rated appliances, and investment in thermal insulation of private buildings which constitutes the most expensive form of energy saving technology.

Household attitude towards financial and environmental concerns on the decision of adoption has important policy implications. It is therefore not surprising that many empirical studies have investigated the matter (for a review see for example Kastner and Stern, 2015). However, most of the literature focuses on one issue or another. We believe that financial and environmental concerns are two faces of the same coin. Behavioural economists have shown that consumer behaviour is complex and rarely follow neoclassical rational-choice theoretical models of decision-making (see for example Kollmuss and Agyeman, 2002). In this respect, considering the joint impact of household environmental and financial concerns on the decision of adoption may shed some light on the puzzle that has plagued academics and policy makers alike in the recent years.

Our empirical investigation proceeds in two steps. In the first stage, we investigate if household environmental and financial concerns induce to different patterns of adoption of energy saving technologies. Unlike the previous literature, we use stochastic dominance methodology to determine if environmental and financial concerns affect household behaviour. Stochastic dominance is a nonparametric procedure that allows us to compare distribution functions of different adoption levels within groups of households. The stochastic dominance methodology allows us to answer questions like: Is what individual *say* actually what they *do* when it comes to investment decisions in energy saving technologies? In doing so we are in a position of testing for the attitude-action gap hypothesis postulated by theoretical models.

Having examined if environmental and financial concerns induce to different patterns of adoption of energy saving technologies, in the second stage our investigation we delve further and analyse the socio-economic determinants of adoption. In this stage we are particularly interested in investigating if households that reported different degrees of financial and environmental concerns also feature diverse socio-economic profiles. To investigate this issue, we turn to a parametric model specification and estimate the probability of the adoption of environmentally and financially minded households as a function of a number of socio-economic factors. In line with the extant literature covariates include socio-economic factors such as age, gender, education, family size, and income (see for example Kastner and Stern, 2015; Mills and Schleich, 2010; Urban et al., 2012).

The present paper extends the existing literature in several ways. First, the results of the stochastic dominance analysis show that environmental and financial concerns play an important role in the decision of adopting energy saving technologies, thus paving the way for policy actions targeted at enhancing consumer awareness. Second, the parametric analysis reveals that environmentally and financially concerned households exhibit different socio-economic profiles. We find that environmentally minded, highly educated households living in urban areas with large family size are more likely to adopt than their counterparts with low level of education living in rural areas.

On the other side, income is an important factor explaining adoption of economically concerned household. The proposed methodological approach is the third contribution of the paper. The stochastic dominance procedure adopted in this paper is extremely flexible as it is robust to departures of cross-dependency between random variables, serial correlation and unconditional heteroscedasticity (see Linton et al., 2005). This constitutes a significant departure from the traditional stochastic dominance inference procedures which strongly rely on the on the i.i.d. assumption (see for example Barret and Donald, 2003; Davidson and Duclos, 2000). Finally, unlike many other related studies, our analysis is based on a novel dataset the covers a large number of countries across Europe. This large sample allow us to overcome idiosyncratic factors and exploit the heterogeneity across countries. Such comprehensive level of analysis is rarely found in related empirical works.

The paper is structured as follows. Section 2 describes the theoretical background in the light of the related literature. Section 3 introduces the stochastic dominance procedure and discusses the empirical results. Section 4 illustrates the data used in the analysis. Section 5 presents the results on the socio-economic determinants of adoption. Finally, Section 6 presents some concluding remarks and policy implications.

2. Energy Saving Behaviour

A major challenge for academic and policy makers has been how to encourage consumers to adopt environmentally friendly technologies. This is because the motivation that leads consumers to adopt energy-saving activities is complex and not easily identified. It is clear however, that adoption of energy saving technologies is not driven exclusively by rational cost-benefit analysis, but also by less material interests such as environmental awareness, health-related motivation, and habits (see Whitmarsh, 2009). In this respect, the relevant literature makes a distinction between two types of residential energy-saving activities: efficiency investments and curtailments. Jansson et al. (2009) argue that unlike curtailment, efficiency investments are high-involvement activities which require considerable monetary costs for their implementation. For this reason, the authors suggest that decisions to introduce efficiency measures are less driven by moral motivation than curtailment.

A great number of studies provides evidence on the importance of cost-reduction factors (e.g., reducing energy bills, paying less for energy-efficiency appliances) as drivers for both energy investments and curtailments. However, available empirical investigations offer a less clear-cut evidence on the role of environmental concerns on the adoption of energy saving technologies, providing sometimes controversial results.

In the literature, there is general agreement on the fact that the impact of environmental concerns is greater for low cost technologies, so that the attitude-action gap is lower for these technologies (see for example Kastner and Stern, 2015; and Pothitou et al., 2016). However, some studies found that environmental awareness has an impact on high-cost technologies such as photovoltaic systems. For example, Bashiri and Alizadeh (2018) found that environmental concerns and knowledge of renewable energies positively increases the probability of adoption of photovoltaic systems (see also Schleich, 2019; Bergek and Mignon, 2017). Similarly, Urban et al. (2012) find that environmental concerns have a positive effect on the installation of energy efficient appliances.

Consensus literature highlights the fact that environmental and financial concerns are also related to socio-economic factors, for example, low-income households with low level of education are found to be more motivated to save energy for financial reasons in Mills and Schleich (2009). On the other side, Shen et al. (2008) find that young and educated individuals are more likely to express environmental concerns. In the same vein, Poortinga et al. (2002) use socio-demographic variables to explain household energy consumption. The authors find that factors such as income and household size play an important role in the adoption decision. None of the studies known to us have attempted to study the role of environmental and financial concerns on energy conservation in a multi-country context.

3. Stochastic Dominance Inference Procedure for Energy-Saving Behaviour

Below, we first briefly define the criteria of stochastic dominance and we then describe the testing procedure for stochastic dominance adopted in the paper.

3.1 Concepts of Stochastic Dominance

This section presents the conceptual framework for the stochastic dominance procedure. Following standard consumer theory, we assume that households maximize their utility function either: *i*) by minimizing energy costs for financial reasons, or *ii*) by minimizing adverse environmental effects related to their energy consumption; or *iii*) they can have both objectives *i*) and *ii*) in their utility function. In particular, households can increase their welfare by making three types of energy efficiency investments with an increasing monetary cost from low to high. The first type of energy saving investment is classified as low-cost and corresponds to the adoption of low-energy bulbs, which we refer to as "*Lights*". The second type of energy saving investment is the medium-cost adoption of energy-efficiency-rated appliances, which we label as "*Appliances*". Finally, the most expensive energy saving technology considered is the investment in thermal insulation for their property, which we refer to as "*Insulation*" hereafter.

Let W_1 denote the class of all von Neumann-Morgestern type of utility functions, *w*, such that households' utility is decreasing in energy related cost, that is $w' \leq 0.$ Also, let W_2 denote the class of all utility functions in W_1 for which $w'' \leq 0$ (i.e. strict concavity), and W_3 denote a subset of W_{j} for which $\mathrm{u}''' \leq 0$. Let X_1 be and X_2 be two random variables related to adoption of a given energy saving technology. We assume that $\{x_1\}_{k=1}^{n}$ is a vector of α-mixing, possibly dependent observations, and $\{x_2\}_{k=1}^{n}$ is an analogous vector of realizations of X_2. Let $F_1(x)$ and $F_2(x)$ be the cumulative distribution functions of X_1 and X_2 respectively. Using this notation below we briefly define the concepts of first and second order stochastic dominance.

Definition 1. X_1 first order stochastically dominates X_2 , if and only if either:

i) $E[u(X_1)] \geq E[u(X_2)]$ for all $u \in U_1$
ii) $F_1(x) \leq F_2(x)$ for every x with strict inequality for some x.

According to Definition 1 households are averse to increasing levels of energy costs, which is implied by the assumption of strict concavity of the utility function. First order stochastic dominance implies that all utility maximizing households will prefer X_1 to X_2. Second order stochastic dominance implies the usual assumption of diminishing marginal utility a negative second derivative of the household's utility function. More formally, we define second order stochastic dominance[1] as follows:

Definition 2. The prospect X_1 second order stochastic dominates X_2 if and only if either:

i) $E[u(X_1)] \geq E[u(X_2)]$
ii) $\int_{-\infty}^{x} F_1(t)dt \leq \int_{-\infty}^{y} F_2(t)dt$ for every x with strict inequality for some x.

[1] See Levy (1992) for more details on the definition of first and second order stochastic dominance.

According to Definition 2, if X_1 second order stochastically dominates X_2, then the expected household utility from X_1 is at least as great as that from X_2 for all (decreasing and strictly concave) utility functions in the class W_2, with strict equality holding for some utility functions in the class. Note that first order stochastic dominance implies second order, and if X_1 second order stochastically dominates X_2 is consistent, then the mean of X_1 is either greater than, less than, or equal to the mean of X_2.

Testing for stochastic dominance is based on comparing the cumulate distribution functions of the random variables relating to households' attitudes toward financial and environmental issues. However, the true cumulated distribution functions are not known in practice. Therefore, stochastic dominance tests rely on the empirical distribution functions. In the literature several procedures have been proposed to test for stochastic dominance. An early work by McFadden (1989) proposed a generalization of the Kolmogorov-Smirnov test of first and second order stochastic dominance among several prospects (distributions) based on *i.i.d.* observations and independent prospects. Later works by Klecan *et al.* (1991) and Barrett and Donald (2003) extended these tests allowing for dependence in observations and replacing independence with a general exchangeability amongst the competing prospects. In this paper we use the inference procedure suggested in Linton *et al.* (2005) where consistent critical values for testing stochastic dominance are obtained for serially dependent observations. The procedure also accommodates for general dependence amongst the prospects which are to be ranked. Below, we first state the hypotheses under investigation and we then describe the testing procedure for stochastic dominance adopted in the paper.

3.2. The Hypotheses of Interest

Let Ω be the set of households that adopted at least one energy saving technologies. Let $\{X_{i,j}: x_{i,j} \subseteq \Omega\}$ and $\{\bar{\bar{X}}_{i,j}: \bar{\bar{x}}_{i,j} \subseteq \Omega\}$ be the subsets of households that expressed high and low (or no) concern, respectively, in the *i* motivation, for $i = 1,2,$ (i.e. financially concerned, environmentally minded) and let j be the energy-saving technology, for $j = 1, \dots, 3,$ (i.e., lights, appliances, insulation). Let Ψ represents the set households that did not adopt energy saving technologies, so that $\{Y_{i,j}: y_{i,j} \subseteq \Psi\}$ and $\{\bar{\bar{Y}}_{i,j}: \bar{\bar{y}}_{i,j} \subseteq \Psi\}$ denote the subsets of households that expressed high and low concern in *i* the matter, respectively.

To investigate whether households' environmental and financial concerns have an impact on the adoption of energy saving technologies we test a number of related hypotheses. We summarize them below:

Proposition 1: *Highly concerned households adopt more environmentally sustainable technologies than little (or no) concerned households*.

Proposition 2: *Strong financial concerns translate to greater adoption of energy saving technologies*.

Proposition 3: *Households with positive attitude towards environmental matters adopt more than households with little (or no) concerns toward environmental problems*.

Corollary 1: *Low financial concerns lead households to not adopt energy saving technologies.*

Corollary 2: *Negative attitude toward environmental problems leads households to not adopt energy saving technologies.*

Proposition 4: *Strong financial and environmental concerns jointly lead to higher adoption of energy saving technologies*.

Corollary 3: *Households that are jointly strongly concerned about the environmental and financial matters adopt more than households that expressed little (or no) concerns.*

Corollary 4: *Negative attitude toward environment and low financial concerns lead households to avoid adopting energy saving technologies*.

Proposition 5: *Financial concerns lead to greater adoption than environmental concerns*.

Corollary 5: *Households with low (or no) financial concerns adopt more than households with little (or no) environmental concerns.*

To assess the validity of Proposition 1, for each technology *j*, we test the hypothesis that adoption from highly concerned households stochastically dominates the adoption level of households that expressed low (or no) level of concern. To establish the direction of stochastic dominance between $X_{i,j}$ and $\bar{\bar{X}}_{i,j}$, we test the following null hypotheses

$$H_0^1: X_{i,j} \succ_s \bar{\bar{X}}_{i,j},$$

where the operator "$\succ_s$" indicates the dominance relation, and the null hypothesis

$$H_0^2: \bar{\bar{X}}_{i,j} \succ_s X_{i,j},$$

with the alternative hypotheses being the negation of the null hypothesis for both H_0^1 and H_0^2. We infer that households that expressed high level of concern in the *i* matter stochastically dominate households that expressed low level of concerns in the same matter if we accept H_0^1 and reject H_0^2. Conversely, we infer that households that expressed low level of concern stochastically dominate households that expressed high level of concern in the i matter if we accept H_0^2 and reject H_0^1. In cases where neither of the null hypotheses can be rejected, we conclude that the stochastic dominance test statistic is not conclusive.

Proposition 2 and 3 state that households with high concern in the *i* matter stochastically dominate non-adopting households with low (or no) concerns in the same matter. These propositions are meant test for the attitude-action gap hypothesis suggested for example in Flynn et al. (2010). To assess of the validity of these propositions we consider adopting and non-adopting households and test the following null hypotheses

$$H_0^1: X_{i,j} \succ_s \bar{\bar{Y}}_{i,j},$$

and

$$H_0^2: \bar{\bar{Y}}_{i,j} \succ_s X_{i,j},$$

with the alternative hypotheses being the negation of the null hypothesis for both H_0^1 and H_0^2. For each technology, j, we conclude that the adoption for households that are highly concerned in the matter *i* stochastically dominate not adopting households with low concern if we accept H_0^1 and reject H_0^2. On the other hand, we infer that non adopting households with low concern in *i* matter stochastically dominate adopting households with low concern in the same matter if we accept H_0^2 and reject H_0^1. In cases where neither of the null hypotheses can be rejected, we conclude that the stochastic dominance test statistic is not conclusive.

Corollaries 1 and 2 are nuances of Proposition 2 and 3 since they state that non-adopting households that expressed low (or no) concern in the *i* matter stochastically dominate adopting households with a similar level of concern in the same matter. The proposition is meant to answer the following question: Do non-adopting and not (or little) concerned households adopt more than not concerned (or little) adopting households? The validity of these propositions can be assessed by testing that following null hypotheses

$$H_0^1: \bar{\bar{Y}}_{i,j} \succ_s \bar{\bar{X}}_{i,j},$$

and

$$H_0^2: \bar{\bar{X}}_{i,j} \succ_s \bar{\bar{Y}}_{i,j},$$

with the alternative hypotheses being the negation of the null hypothesis for both H_0^1 and H_0^2.

Proposition 4 states that adopting households that expressed jointly strong financial and environmental concerns stochastically dominate adopting households with low (or no) concerns in both matters. To assess the empirical validity of Proposition 4 we consider the intersection, $\Theta_j = (X_{E,j} \cap X_{F,j})$, (that is, the subsets of adopting households that are jointly highly financially and environmentally concerned), and the intersection $\bar{\bar{\Gamma}}_j = (\bar{\bar{X}}_{E,j} \cap \bar{\bar{X}}_{F,j})$ (that is, the subset of households neither (or little) environmentally nor financially concerned) and test the hypotheses

$$H_0^1: \Theta_j \succ_s \bar{\bar{\Gamma}}_j,$$

and

$$H_0^2: \bar{\bar{\Gamma}}_j \succ_s \Theta_j,$$

with the alternative hypotheses being the negation of the null hypothesis for both H_0^1 and H_0^2.

Corollary 3 is closely related to Propositions 2 and 3 in the sense that we test the same hypotheses, but this time we consider the subset of households that expressed both environmental and financial concerns. Let $\bar{\bar{\Upsilon}}_j = (\bar{\bar{Y}}_{E,j} \cap \bar{\bar{Y}}_{F,j})$ be the intersection of $\{\bar{\bar{Y}}_{E,j}: \bar{\bar{y}}_{E,j} \subseteq \Psi\}$ and $\{\bar{\bar{Y}}_{F,j}: \bar{\bar{y}}_{F,j} \subseteq \Psi\}$ where $\bar{\bar{Y}}_{E,j}$ and $\bar{\bar{Y}}_{F,j}$ are the subsets households that did not adopt energy saving technologies and expressed low (or no) concerns on environmental and financial matters, respectively. To investigate the validity of Corollary 3, we test the hypothesis that adopting households with low (or no) concerns in the both matters stochastically dominate non-adopting households with similar level of concern in the both matters. Therefore, the null hypotheses are

$$H_0^1: \Theta_j \succ_s \bar{\bar{\Upsilon}}_j,$$

and

$$H_0^2: \bar{\bar{\Upsilon}}_j \succ_s \Theta_j,$$

with the alternative hypotheses being the negation of the null hypothesis for both H_0^1 and H_0^2.

For completeness, Corollary 4 states that non-adopting households that expressed low (or no) concerns in both matters stochastically dominate adopting households that also expressed low (or no) concerns in both matters jointly. To assess this proposition, we test the following null hypotheses

$$H_0^1: \bar{\bar{\Upsilon}}_j \succ_s \bar{\bar{\Theta}}_j,$$

and

$$H_0^2: \bar{\bar{\Theta}}_j \succ_s \bar{\bar{\Upsilon}}_j,$$

where $\bar{\bar{\Theta}}_j$ is the intersection

$$\bar{\bar{\Theta}}_j = (\bar{\bar{X}}_{E,j} \cap \bar{\bar{X}}_{F,j}),$$

and $\bar{\bar{X}}_{E,j}$ and $\bar{\bar{X}}_{F,j}$ are the subsets households that did adopt energy saving technologies and expressed low (or no) concerns on environmental and financial matters, respectively. As before the alternative hypotheses are the negation of the null hypothesis for both H_0^1 and $H_{0.}^2$

In Proposition 5 we assess the hypotheses that financial concerns overtake environmental concerns in the decision of adopting energy saving technologies. In the literature it is not clear if in the motivation that leads households to adopt energy saving technologies financial matters impact more than environmental concerns. For example, Whitmarsh (2009) finds that economic factors overtake environmental motivations as driving factors for curtailments and energy investments. However, the literature is not conclusive on the motivations that lead households to adopt energy-saving activities (see Steg, 2008). For this reason, under the null hypotheses we state that

$$H_0^1 \colon \bar{\bar{X}}_{F,j} \succ_s X_{E,j},$$

and

$$H_0^2 \colon X_{E,j} \succ_s \bar{\bar{X}}_{F,j,}$$

with the alternative being the negation of the null hypothesis for both H_0^1 and $H_{0.}^2$

Corollary 5 tests the hypothesis that even when households express low (or no) concerns, financial matters overtake environmental matters when it comes to investment decisions in energy saving technologies. Accordingly, we state the following null hypotheses:

$$H_0^1 \colon \bar{\bar{X}}_{F,j} \succ_s \bar{\bar{X}}_{E,j},$$

and

$$H_0^2 \colon \bar{\bar{X}}_{E,j} \succ_s \bar{\bar{X}}_{F,j},$$

with the alternative being the negation of the null hypothesis for both H_0^1 and $H_{0.}^2$

3.3. Testing Procedure for Stochastic Dominance

To test the hypotheses above we consider functional of distribution functions of the random variables in Ω and Ψ. Below we specify the testing procedure for Proposition 1 only, as all the other hypotheses can be tested in a similar fashion.

Let $D_{i,j}^s(x)$ and $D_{i,j}^s(\bar{\bar{x}})$ be the empirical distributions of $X_{i,j}$ and $\bar{\bar{X}}_{i,j}$, respectively. To test the null hypothesis in Proposition 1 we test that

$$H_0\colon D^s_{i,j}(x; F_{i,j}) \leq D^s_{i,j}(\bar{\bar{x}}; F_{i,j}),$$

$\forall\, x \in \mathbb{R}, s = 1{,}2$. The alternative hypothesis is the negation of the null, that is

$$H_1\colon D^s_{i,j}(x; F_{i,j}) > D^s_{i,j}(\bar{\bar{x}}; F_{i,j}),$$

$\forall\, x \in \mathbb{R}, s = 1{,}2$. To construct the inference procedure, we consider the Kolmogorov-Smirnov distance between functionals of the empirical distribution functions of $X_{i,j}$ and $\bar{\bar{X}}_{i,j}$ and define the test statistic as

$$\widehat{\Lambda} = min\ sup_{x\in\mathbb{R}} \sqrt{N}\left[\widehat{D}^s_{i,j}\left(x; \hat{F}_{i,j}\right) - \widehat{D}^s_{i,j}\left(\bar{\bar{x}}; \hat{F}_{i,j}\right)\right], \tag{1}$$

where

$$\widehat{D}^s_i\left(x; \hat{F}_{i,j}\right) = \frac{1}{N(s-1)!} \sum_{t=1}^{T} 1\left(X_{i,j} \leq x\right)\left(x - X_{i,j}\right)^{s-1}, \tag{2}$$

and $\widehat{D}^s_{i,j}(\bar{\bar{x}}; \hat{F}_{i,j})$ is similarly defined. Linton *et al.* (2005) show that under suitable regularity conditions $\widehat{\Lambda}$ converges to a functional of a Gaussian process. However, the asymptotic null distribution of $\widehat{\Lambda}$ depends on the unknown population distributions, therefore in order to estimate the asymptotic *p*-values of the test we use the overlapping moving block bootstrap method. The bootstrap procedure involves calculating the test statistics $\widehat{\Lambda}$ using the original sample and then generating the subsamples by sampling the overlapping data blocks. Once that the bootstrap subsample is obtained, one can calculate the bootstrap analogue of $\widehat{\Lambda}$. In particular, let B be the number of bootstrap replications and b the size of the block. The bootstrap procedure involves calculating the test statistics $\widehat{\Lambda}$ in Eq. (1) using the original sample and then generating the subsamples by sampling the $N - b + 1$ overlapping data blocks. Once that the bootstrap subsample is obtained one can calculate the bootstrap analogue of $\widehat{\Lambda}$. Defining the bootstrap analogue of Eq. (1) as

$$\widehat{\Lambda}^{*} = \min \sup_{x\in\mathbb{R}} \sqrt{N}\left[\widehat{D}^{s*}_{i,j}\left(x; \hat{F}_{i,j}\right) - \widehat{D}^{s*}_{i,j}\left(\bar{\bar{x}}; \hat{F}_{i,j}\right)\right] \tag{3}$$

where

$$\widehat{D}^{*}\left(\hat{F}\right) = \frac{1}{N(s-1)!} \sum_{h=1}^{N} \{1\left(X^*_{i,j} \leq x\right)\left(x - X^*_{i,j}\right)^{s-1} - \omega(h,b,N) 1(\bar{\bar{X}}^*_{i,j} \leq \bar{\bar{x}})\left(\bar{\bar{x}} - \bar{\bar{X}}^*_{i,j}\right)^{s-1}\},$$

and

$$\omega(h,b,N) = \begin{cases} \kappa/b & if \quad \in [1, b-1] \\ 1 & if\ i \in [1, N-b+1] \\ (N-i+1)/b & if\ [N-b+2, N] \end{cases}$$

The estimated bootstrap *p*-value function is defined as the quantity

$$p^*(\hat{\Lambda}) = \frac{1}{N-b+1}\sum_{h=1}^{N-b+1} 1(\Lambda^* \geq \hat{\Lambda}).$$

Under the assumption that the random variables $X_{i,j}$ and $\bar{\bar{X}}_{i,j}$ are α-mixing with $\alpha(j) = O(j^{-\delta})$, for some $\delta > 1$, when $B \to \infty$ the expression in Eq. (3) converges to Eq. (1). Also, asymptotic theory requires that $b \to \infty$ and $b/N \to 0$ as $N \to \infty$.

4. Data and Empirical Results

This study exploits data from the *Second consumer market study on the functioning of the retail electricity markets for consumers in the EU* (2017) that investigates consumers' awareness, attitude and experience with electricity services. The survey, in the form of questionnaire, was targeted to individuals (aged from 18 to 95) who were fully or jointly in charge of paying the electricity bill in their household. The original dataset includes 29,119 interviews conducted with a mixed-mode approach (online, telephone, and face-to-face) across 30 European countries (28 countries in the European Union in addition to Iceland and Norway).

Households environmental and financial attitudes were detected by selecting the following questions in the questionnaire: "*It is important for me to save energy for financial reasons*" and "*It is important for me to save energy for environmental reasons*". We re-arranged the information contained in the original dataset, which allowed answers on 11 levels, in three groups: low (0-3), medium (4-7), and high (8-11) financial and environmental concerns.

After data cleaning our sample includes 23,808 households. Table 1 describes the sample. Note that the adoption of energy efficient appliances and of light emitting diodes is explored for tenants and homeowners. However, insulation measures are considered for home-owners only.

Table 1. Descriptive Statistics

	Number of Observations	*Frequency*
Panel A: Technologies		
Energy saving light bulbs		
Non adopters	3,088	12.97
Adopters	20,720	87.03
Energy-efficient appliances		
Non adopters	5,981	25.12
Adopters	17,827	74.88
Insulation		
Non adopters	15,572	65.41
Adopters	8,236	34.59
Panel B: Attitude		
Financially concerned households		
No/Low financial concerns	1,542	6.48
Medium	6,420	26.97
High financial concerns	15,820	66.57
Environmentally minded households		
No/Low financial concerns	2,176	9.14
Medium	8,265	34.72
High financial concerns	13,361	56.14
Panel C: Socio-Economic Variables		
Age (mean)	42.05	-
Gender		
Male	11,672	49.03
Female	12,136	50.97
Education		
Primary education	2,984	12.53
Secondary education	10,900	45.78
Tertiary education	9,924	41.68
Population density		
Urban areas	13,806	57.99
Rural areas	10,002	42.01
Income		
High/Medium High	11,584	48.66
Low/Medium Low	12,224	51.34
Family size		
1	9,178	38.55
2	6,471	27.18
3	5,495	23.08
4	1,901	7.98
5	543	2.28
5>	136	0.92
Family size (mean)	3.2	-

4.4. Stochastic Dominance Results

Table 2 reports the results of the stochastic dominance test in relation to the propositions stated above. In particular, in columns 1 and 2 the propositions under assessment and the corresponding null hypotheses are reported, respectively. Columns 3-8 report the *p*-values of the stochastic dominance test in relation to the three different energy saving technologies considered in this work. The *p*-values are reported for the first and second order stochastic dominance referred to as “FSD” and “SSD”, respectively. The *p*-values were obtained using a number of $B = 1000$ bootstrap replications.

Table 2. Test for Stochastic dominance results for the assessment of Propositions 1-5 and their related corollaries.

	Null Hypotheses	*Energy saving technologies*					
		Bulbs		***Appliances***		***Insulation***	
		FSD	SSD	FSD	SSD	FSD	SSD
Proposition 1	$H_0^1: X_{F,j} \succ_s \bar{\bar{X}}_{F,j}$	0.962	0.554	0.999	0.935	0.999	0.941
	$H_0^2: \bar{\bar{X}}_{F,j} \succ_s X_{F,j}$	0.000	0.001	0.000	0.000	0.000	0.000
	$H_0^1: X_{E,j} \succ_s \bar{\bar{X}}_{E,j}$	0.999	0.985	0.999	0.982	0.666	0.961
	$H_0^2: \bar{\bar{X}}_{E,j} \succ_s X_{E,j}$	0.000	0.000	0.000	0.000	0.000	0.000
Proposition 2	$H_0^1: X_{F,j} \succ_s \bar{\bar{Y}}_{F,j}$	0.950	0.637	0.999	0.949	0.999	0.987
	$H_0^2: \bar{\bar{Y}}_{F,j} \succ_s X_{F,j}$	0.000	0.002	0.000	0.000	0.000	0.000
Proposition 3	$H_0^1: X_{E,j} \succ_s \bar{\bar{Y}}_{E,j}$	0.999	0.652	0.711	0.952	0.000	0.000
	$H_0^2: \bar{\bar{Y}}_{E,j} \succ_s X_{E,j}$	0.000	0.000	0.000	0.000	0.697	0.896
Corollary 1	$H_0^1: \bar{\bar{Y}}_{F,j} \succ_s \bar{\bar{X}}_{F,j}$	0.000	0.000	0.653	0.684	0.795	0.595
	$H_0^2: \bar{\bar{X}}_{F,j} \succ_s \bar{\bar{Y}}_{F,j}$	0.999	0.889	0.865	0.577	0.071	0.019
Corollary 2	$H_0^1: \bar{\bar{Y}}_{E,j} \succ_s \bar{\bar{X}}_{E,j}$	0.000	0.000	0.538	0.205	0.999	0.967
	$H_0^2: \bar{\bar{X}}_{E,j} \succ_s \bar{\bar{Y}}_{E,j}$	0.999	0.972	0.981	0.927	0.000	0.000
Proposition 4	$H_0^1: \Theta_j \succ_s \bar{\bar{\Gamma}}_j$	0.999	0.969	0.999	0.956	0.999	0.983
	$H_0^2: \bar{\bar{\Gamma}}_j \succ_s \Theta_j$	0.000	0.000	0.000	0.000	0.000	0.000
Corollary 3	$H_0^1: \Theta_j \succ_s \bar{\bar{\Upsilon}}_j$	0.999	0.979	0.999	0.968	0.000	0.000
	$H_0^2: \bar{\bar{\Upsilon}}_j \succ_s \Theta_j$	0.000	0.000	0.000	0.000	0.999	0.963
Corollary 4	$H_0^1: \bar{\bar{\Upsilon}}_j \succ_s \bar{\bar{\Theta}}_j$	0.999	0.987	0.237	0.563	0.000	0.000
	$H_0^2: \bar{\bar{\Theta}}_j \succ_s \bar{\bar{\Upsilon}}_j$	0.000	0.000	0.945	0.688	0.994	0.973
Proposition 5	$H_0^1: \bar{\bar{X}}_{F,j} \succ_s X_{E,j}$	0.745	0.796	0.922	0.629	0.934	0.549
	$H_0^2: X_{E,j} \succ_s \bar{\bar{X}}_{F,j}$	0.937	0.528	0.882	0.554	0.000	0.002
Corollary 5	$H_0^1: \bar{\bar{X}}_{F,j} \succ_s \bar{\bar{X}}_{E,j}$	0.000	0.003	0.888	0.716	0.268	0.660
	$H_0^2: \bar{\bar{X}}_{E,j} \succ_s \bar{\bar{X}}_{F,j}$	0.986	0.686	0.624	0.455	0.945	0.452

Note: The table reports the *p*-values of the test for first and second order stochastic dominance. The *p*-values are obtained using the non- parametric block-bootstrap method with $B = 1000$ replications. The propositions of interest are: **Proposition 1**: Highly concerned households adopt more environmentally sustainable technologies than little (or no) concerned households. **Proposition 2**: Strong financial concerns translate to greater adoption of energy saving technologies. **Proposition 3**: Households with positive attitude towards environmental matters adopt more than households with little (or no) concerns toward environmental problems. **Corollary 1:** Low financial concerns lead households to not adopt energy saving technologies. **Corollary 2**: Negative attitude toward environmental problems leads households to not adopt energy saving technologies. **Proposition 4:** Strong financial and environmental concerns jointly lead to higher adoption of energy saving technologies. **Corollary 3:** Households that are jointly strongly concerned about the environmental and financial matters adopt more than households that expressed little (or no) concerns. **Corollary 4:** Negative attitude toward environment and low financial concerns lead households to avoid adopting energy saving technologies. **Proposition 5**: Financial concerns lead to greater adoption than environmental concerns. **Corollary 5:** Households with low (or no) financial concerns adopt more than households with little (or no) environmental concerns.

Looking now at the results for Proposition 1, in Table 2 it appears that consumers' attitude play an important part in the adoption of energy saving technologies as the null hypotheses $H_0^1\colon X_{i,j} \succ_s \bar{\bar{X}}_{i,j}$ are not rejected. Conversely, the null hypotheses $H_0^2\colon \bar{\bar{X}}_{i,j} \succ_s X_{i,j}$ are rejected in favour of the alternative hypotheses. Therefore, we conclude that highly concerned adopting households stochastically dominate adopting households that expressed low (or no) concern in financial or environmental matters. Remarkably, this result holds no matter the cost of the technology under consideration and the order of stochastic dominance.

Coming now to Propositions 2 and 3 we can see that the results in Table 2 highlights important differences when the cost of adopting energy saving technologies is taken into consideration. With respect to Proposition 2, the null hypotheses $H_0^1\colon X_{F,j} \succ_s \bar{\bar{Y}}_{F,j}$ are not rejected at first order stochastic dominance for all three technologies, whereas $H_0^2\colon \bar{\bar{Y}}_{F,j} \succ_s X_{F,j}$ are rejected in all cases. Therefore, we can conclude that highly financially concerned adopting households first order stochastically dominate adopting households that expressed low (or no) interest on financial curtailments. Looking at Proposition 3, the results relating low-to-medium costs energy saving technologies are not different. However, when it comes to investing in costly property thermal insulation the null hypothesis $H_0^2\colon \bar{\bar{Y}}_{E,j} \succ_s X_{E,j}$ cannot be rejected, whereas the null hypothesis $H_0^1\colon X_{E,j} \succ_s \bar{\bar{Y}}_{E,j}$ is rejected in favour of the alternative hypothesis. We thus conclude that not-adopting households with high environmental concerns first order stochastically dominate adopting households with low (or no) environmental concerns. The result that economic factors have a greater impact on the adoption of energy saving technologies than environmental factors is also found in related literature (see for example Whitmarsh and O'Neill,2010), confirming the attitude-action gap hypothesis for high-cost technologies.

The assessment of the validity of Corollary 1 and 2 gives mixed results for the data at hand. From column 3 and 4 in Table 2 we do not reject the null hypotheses $H_0^1\colon \bar{\bar{X}}_{i,j} \succ_s \bar{\bar{Y}}_{i,j}$, but the null hypotheses $H_0^1\colon \bar{\bar{Y}}_{i,j} \succ_s \bar{\bar{X}}_{i,j}$ are rejected. Therefore, we can infer that in the case of adoption of low-cost technology, low level of financial or environmental concerns still lead households to adopt energy saving technologies. However, the picture changes when we consider more expensive technologies such as thermal insulation, where we do no reject the null hypothesis that $H_0^1\colon \bar{\bar{Y}}_{i,j} \succ_s \bar{\bar{X}}_{i,j}$, whereas the hypothesis $H_0^1\colon \bar{\bar{X}}_{i,j} \succ_s \bar{\bar{Y}}_{i,j}$ can be rejected. Therefore, in this case we can conclude that low motivation toward environmental or financial matters leads households to act accordingly and not to invest in expensive insulation technologies. Interestingly enough, the test results for the middle cost energy efficiency-rated-appliances are not conclusive as in column 5 and 6 both null hypotheses can't be rejected.

Regarding Proposition 4, from Table 2 we can infer that adopting households that are highly concerned in both environmental and financial matters first order stochastically dominate their counterpart with low (or no) concerns, no matter the cost of the technology under consideration. In this respect, these results are consistent with the conjecture in Proposition 1, where environmentally and financially minded households were considered separately. The results from the assessment of Proposition 4 can only make our conclusion that positive attitude toward environmental or financial matters increase households' energy-saving investments. The same results hold true for Corollary 3 and 4 where the findings exactly match with those for Proposition 2 and 3, thus strengthening the validity of our conjectures.

Finally, coming to Proposition 5, from Table 2 we can infer that financial curtailments are important when it comes to adoption of costly insulation technology, but in the case of adoption of less expensive technologies there is no clear winner since in the latter case the stochastic dominance tests are not conclusive. In other words, a statement of "high concern" in environmental matters translates to action only for low-to-middle cost technologies, but not for costly thermal insulation technology. This result is reinforced when we looked at the test results for Corollary 5. In this case we do not reject the null at first order only for the hypothesis

$$H_0^2: \bar{\bar{X}}_{E,j} \succ_s \bar{\bar{X}}_{F,j}$$

for the adoption low energy bulbs only, whereas for the other more expensive technologies the test statistic is not conclusive. Therefore, we conclude that households with low (or no) environmental concerns stochastically dominate households with low (or no) financial concerns for the adoption of the low-cost bulbs only.

5. Financial and Environmental Concerns and Socio-Economic Determinants

In Section 4 the stochastic dominance analysis has revealed several insights on the impact of financial and environmental concerns on the adoption patterns of energy saving technologies. However, the nonparametric analysis is rather silent on the socio-economic background of adopting households. Consensus literature supports the view that demographic and socio-economic factors play a major role on consumer behaviour. For example, factors such age, gender, education level and income were found to increase the probability of adoption in Urban et al. (2012); see also Pothitou et al., (2016) and Schleich (2019).

Against this background, we now turn to parametric modelling and estimate a logit model to further delve on the relationship between the type of concerns investigated in this paper and the profile of economic agents.

For i the concern, the probability of adopting the technology j is given by

$$\pi_k = \Pr(Adopt_k \,|X_k = x_k) = \frac{e^{x_k'\beta}}{1+e^{x_k'\beta}} \qquad (4)$$

where the dependent variable, π_k, is the probability of adopting conditional to vector X of covariates. In particular, $X_k = \{Age_k, Fem_k, SecEdu_k, Univ_k, City_k, Inc_k, FamSize_k\}$ where *Age* and *FamSize* are a continuous variable for age of the survey respondent and the number of household members, respectively. The covariate *Fem* is a dummy variable for gender that takes value zero for male and one for female. The covariate *SecEdu* captures the effect of education attainment and is a discrete variable that takes value one if the respondent had secondary level of education and zero otherwise. Similarly, the dummy *Univ* takes value one if the respondent had tertiary level of education and zero otherwise. The dummy variable *City* takes value one if the respond was resident in large urban areas and zero elsewhere. Finally, *Inc* is a dummy variable that takes value zero for medium-low income households and one for medium-high income household.

Table 3 reports the estimation results for six different models.[1] We refer to these models as M1-M6, respectively. In particular, models M1, M3 and M5 relate to the specification with EM_k as dependent variable, and models M2, M4 and M6 refer to the logit models that have FM_k as dependent variable. The technology under consideration is reported in the first row of Table 3.

The estimation results in Table 3 allow us to compare the probability of adoption of the *k* respondent with the profile in base line model where a low income (low education attainment) male respondent living in rural areas with little or no concern in the *i* matter is considered.

Looking at the results in Table 3 it appears that gender is an important determinant of energy saving technology adoption since the estimated coefficients for Fem_k are significant in all the estimated models, thus indicating that women have a higher probability of adopting energy efficient technologies no matter the cost or the concern under consideration. The effect, however, is stronger for households that expressed environmental concerned. Being older also increase the probability of adoption for environmentally concerned households, no matter the cost of the technology under consideration, whereas Age_k is not significant in models M2 and M6. Interestingly, the estimated coefficient is significant and of the opposite sign in model M4, however the estimated parameter is very small. Such a small the estimated coefficient casts some doubts on the actual impact of this covariate on probability of adoption. This result support the view expressed in Trotta (2018) that older households may have higher

[1] Note the estimation results in Table 3 refer to the model with the subsample of households that reported either financial *or* environmental concerns, estimation results for the subsample of households that reported environmental *and* financial concerns are not reported, but available on request.

expected returns from adoption of energy saving technologies than their younger counterpart (see also Mills and Schleich, 2012).

Considering the effect of education, the estimation results for M1, M3 and M5 highlight that higher education attainment increases the probability of adopting energy-saving technology for environmentally minded households, no matter the cost of the technology under consideration. The same in not true for financially concerned households where the covariates for education are significant for thermal insulation only.

Looking at the results for $FamSize_k$ it appears that the estimated coefficients are also positive and significant in all estimated models but M5, thus supporting the results in Urban et al. (2012). It is interesting to note that the estimated coefficients for this covariate are greater in magnitude in M2, M4 and M6. These findings suggest that the higher average costs of living incurred by larger families makes the adoption of the insulation technologies more likely.

As for income, estimation results in Table 3 show that lower income increases the probability of adoption suggesting that financial incentives are more effective for low income households. These results support the findings in Kastner and Stern (2015) (see also Sütterlin et al., 2011 and Mills and Schleich, 2012).

Finally, living in large urban areas increases the probability of adoption of environmentally concerned respondents, but the same is not true for financially minded households as the estimated parameters for *City* are significant in models M1, M3 and M5, but not in the remaining models. Similar results are found in Kastner and Stern (2015) where a positive correlation between population density and energy efficiency investments was found.

Table 3. Determinants of adoption for environmentally concerned (EM) and financial minded (FM) households.

Dependent variable:	*Lights*		*Appliances*		*Insulation*	
	EM	FM	EM	FM	EM	FM
	M1	M2	M3	M4	M5	M6
Age_k	0.019***	-0.003	0.017***	-0.006**	0.020***	0.002
	(0.002)	(0.002)	(0.002)	(0.003)	(0.004)	(0 .004)
Fem_k	0.520***	0.316***	0.579***	0.373***	0.596***	0.284***
	(0.053)	(0.061)	(0.061)	(0.068)	(0.098)	(0.108)
$SecEdu_k$	0.372***	-0.147	0.473***	-0.095	0.320**	-0.267
	(0.080)	(0.107)	(0.091)	(0.118)	(0.156)	(0.208)
$Univ_k$	0.610***	-0.153	0.664***	-0.075	0.435***	-0.186
	(0.084)	(0.109)	(0.095)	(0.120)	(0.160)	(0.211)
$City_k$	0.118**	-0.005	0.166***	0.001	0.182*	-0.020
	(0.054)	(0.062)	(0.062)	(0.068)	(0.102)	(0.111)
Inc_k	0.044	-1.512***	0.016	-1.612***	0.099	-1.580***
	(0.053)	(0.073)	(0.061)	(0.083)	(0.096)	(0.137)
$FamSize_k$	0.063***	0.143***	0.047*	0.138***	0.065	0.173***
	(0.024)	(0.029)	(0.027)	(0.032)	(0.043)	(0.051)
Const	0.249	3.068***	0.457**	3.310***	0.293	3.000***
	(0.156)	(0.200)	(0.178)	(0.222)	(0.305)	(0.383)
Observations	13,906	15,509	12,261	13,55	4,768	5,146
Log Likelihood	-5,008.86	-4,005.43	-3,979.15	-3,319.69	-1,586.705	-1,317.93
Akaike Inf. Crit.	10,033.74	8,026.87	7,974.31	6,655.38	3,189.41	2,651.87

Note: the table reports the estimation results of the logit specification for six estimated models labelled as M1-M6. Note that: *), **) and ***) denote a significant level at 10%, 5% and 1%, respectively.

6. Conclusion and Policy implications

Policy makers in the EU have set binding targets of energy efficiency[2] that pivot on several actions including reducing energy consumption for households and businesses as well as improving energy performance in buildings. In spite of the implementation of the energy efficiency legislation and ambitious energy efficiency programmes in Europe, empirical evidence shows that energy consumption is still above the targets (see for example the report on Energy, Transport and Environmental Statistics, 2019).

Against this background, we study the households' adoption of energy efficient technologies using a large dataset of thirty European countries in relation to their environmental and financial concerns. We corroborate the evidence that households' decision of adopting energy efficient technologies is not exclusively based on rational

[2] At least 32.5% by 2030, relative to a 'business as usual' scenario. ((EU) 2018/2002 , (EU) 2018/844).

cost-benefit analysis by showing that non-economic factors such as environmental concerns also drive adoption behaviour.

Using stochastic dominance methodology we show that adopting households that are highly concerned in environmental or/and financial matters adopt more energy efficient technologies than their counterpart with low (or no) concerns, no matter the cost of the technology under consideration (Proposition 1 and 4). However, the stochastic dominance analysis results suggest that economic factors mitigate the effect of environmental and financial attitudes on the adoption behaviour, supporting the attitude-action gap hypotheses (see also Corraliza and Berenguer, 2000; Trotta et al. 2018). A statement of "high concern" in environmental matters translates to action only for low-to-middle cost technologies (low-energy bulbs and energy efficient appliances, respectively), but not for costly thermal insulation technology (Proposition 3). Similarly, the comparison between environmental and financially concerned households shows that environmental concern is a stronger determinant than financial concern for low-medium cost technologies, while financially concerned households adopts more high cost technologies compared to environmental concerned households (Proposition 5). Conversely, low motivation toward environmental or financial matters leads households to act accordingly and not to invest in expensive insulation technologies (Corollary 1 and 2).

Looking at the socio-economic profiles of different households it is found that environmentally minded and financially concerned households who have adopted energy-saving technologies feature rather different socio-economic background: educated households living in urban areas are more likely to be environmental concerned whereas household with medium-low income are more likely to be financially concerned.

Our results show that, in addition to traditional measures aiming at financing building energy renovation and at subsidising the purchase of energy efficient appliances, actions that increase financial and environmental awareness (see, for instance, the Intelligent Energy – Europe (IEE) action) directly contribute to achieve greater levels of adoption. Information campaigns are low cost policy instruments that do not require the deployment of financial tools and impose low bureaucratic burden on citizens and institutions. In this respect our results suggest that information measures to promote reduction in energy consumption across EU Member States may be used to support more expensive policy tools such as subsidies, loans and tax incentives. In this respect, our findings may be relevant to inform policy setters looking for feasible ways to foster the adoption of energy saving technologies.

Moreover, by separating the behaviour of environmentally and financially concerned households we can explore the different effect of the value-action gap across technologies and subjects. In the same line, our estimates delineate a profile of environmentally and financially households helping in identifying the most appropriate recipients of specific policy measures.

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