Investment in Energy Efficiency, Adoption of Renewable Energy and Household Behavior: Evidence from OECD Countries

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ABSTRACT

There are possible synergies between the decision to invest in energy efficiency measures and to adopt renewable energy, in the sense that the former reduces energy demand so that the latter can further cut future greenhouse gas (GHG) emissions, and which has great potential in the residential sector. Much work has been done in the residential sector on demand for clean energy and on investment in energy efficiency, but to our knowledge there is no specific study that investigates the relationship between the two. This paper fills a gap in the literature, and first shows theoretically that there are relationships of substitution or complementarity between the two decisions depending on the threshold of the cross effect related to the environmental motivation of the consumer. Second, the paper empirically shows that the two decisions are positively interrelated due to unobserved characteristics that determine both decisions. Third, the paper provides differential impact of energy poverty, split incentive problem, dwelling characteristics, commitment and trust on the two decisions. Finally, the paper investigates household characteristics that significantly affect the joint adoption of energy efficient and renewable energy technologies. This contribution can serve to define incentive policies to advance the energy transition.

Keywords: Energy efficiency, renewable energy, household behavior, bivariate probit

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1. INTRODUCTION

Most of the world's electricity (60%) is consumed in residential and commercial buildings (IEA, 2008a). Specifically, residential buildings contribute 23% to global final energy demand (IEA, 2007) and 17% to world CO_2 emissions (OECD/IEA, 2015). Moreover, cooking, lighting, water heating, appliances and space heating in the residential sector account for 5%, 5%, 16%, 21% and 53%, respectively (IEA, 2008b). Therefore, there is great potential to reduce overall energy demand in the residential sector. In order to reduce the amount of energy used to get the same service, a household can decide to invest in energy efficient technology that results in saving energy. In 2014 for example, improvements in energy efficiency were driven by space heating efficiency improvements (e.g., following home renovation), water heating, lighting and appliances in residential buildings (IEA/OECD, 2014). Energy conservation actions can also be curtailments (Jansson et al., 2009), which refer to behavior changes such as scheduling, turning off lights, cutting down on heating or air conditioning and switching off standby mode. By reducing its consumption of energy,

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a household contributes to reductions in future greenhouse gas (GHG) emissions. In one policy scenario of the International Energy Agency (IEA), 72% of the global decrease in CO_2 emissions between 2010 and 2020 will come from energy efficiency improvements (Knittel et al., 2014).

There are some possible synergies between energy efficiency measures and renewable energy adoption in the sense that the former reduces energy demand so that the latter can further cut future GHG emissions. A household can also invest in renewable energy by installing solar panels or wind turbines, which represented a share of 19% of world final energy consumption in 2012 (RENS21, 2014).This investment produces clean energy and contributes to reducing CO_2 emissions. For example, the deployment of renewable energy could reduce annual CO_2 emissions by 8.6 Gt by 2030 (IRENA, 2014). Additionally, the IRENA (2014) report states that such emissions savings, combined with energy-efficiency gains, would be sufficient to set the world on a path to prevent catastrophic climate change. Furthermore, Dato (2016) shows that it favors full transition to the sole use of renewable energy. Though investments in both energy efficiency and renewable energy are costly, they yield future gains that make them profitable after several years of use.

Thus, clean energy adoption and investment in energy efficiency are both important for a transition to a green economy. There is considerable literature on either demand for clean energy (Gerpott and Mahmudova, 2010; Sardianou and Genoudi, 2013; Zhai and Williams, 2012) or investment in energy efficiency (Dietz et al., 2009; Heslop et al., 1981; Howarth, 1997; Urban and Ščasný, 2012) in the residential sector. To our knowledge, there is no specific study that investigates household behavior with respect to joint adoption of renewable energy and investment in energy efficiency; and the relationship between the two. This paper fills a gap in the literature and aims to analyze (i) the relationship between adoption decisions of renewable energy and energy efficient technologies and (ii) the differential impact of the factors across the two decisions. The paper makes four contributions. First, we use a simple theoretical model to investigate the possible relationships between the decisions to invest in energy efficiency and in renewable energy. In this model, we assume that a household devotes its energy budget to buy non-clean energy and to undertake investments in energy efficiency and in renewable energy, which contribute to a transition to a low carbon economy. The household gets some private or direct utility for using energy services (non-clean and renewable energy). The level of the non-clean energy service and that of the renewable energy service depend on the level of investment in energy efficiency. The household may also gain some additional environment-related satisfaction due to the contribution of the investments in energy efficiency and in renewable energy in protecting the environment. This may depend on the cross effect of the two decisions. We show that there is a cross effect threshold below (resp. above) which investment decisions in energy efficiency and in renewable energy of the household are substitutes (resp. complements). As a consequence, there are relationships between the two decisions.

The theoretical model is followed by empirical investigations of the relationships between the two decisions. We explore whether the decision to adopt renewable energy and to invest in energy efficiency in the residential sector are related. We use a bivariate probit (biprobit) model for the joint decision. The biprobit model allows us to analyze the differential impact of the factors across the two decisions. Additionally, we investigate the determinants of the joint adoption of renewable energy and energy efficient technologies by computing a joint probability of adoption from the results of the biprobit model. Basically, we intend to explain why some households decide to invest both in energy efficiency and in renewable energy, while others decide to only invest in renewable energy or to only invest in energy efficiency, or to do nothing. The household that only adopts renewable energy or only reduces its energy consumption, contributes to the energy transition better than the household who does nothing, and less than the one who undertakes the two investments. For the two empirical investigations, we use the survey on Environmental Policy and Individual Behavior Change (EPIC) from the Organization for Economic Co-operation and Development (OECD). This survey was carried out in 2008 and 2011 across a total of fifteen countries and several areas (energy, food, transport, waste and water) and provides evidence on what affects household decision-making. Precisely, it provides information about socio-economic and environmental factors, attitudes and policy at the household level that can influence actual household decisions to invest in energy efficiency and to adopt renewable energy.

Second, the results of the biprobit model show that there is a positive interrelation between the decision of the household to invest in energy efficiency and to adopt renewable energy due to unobserved characteristics such as environmental motivations. In fact, environmental conscientiousness as a true environmental motivation is not observed and may lead to such a positive correlation, in the sense that a more pro-environmental household is more likely to invest in energy efficiency and in renewable energy. Thus, the bivariate probit model is more appropriate than separate univariate probit models. Third, the paper provides evidence about factors that affect the probability of adopting renewable energy and that of investing in energy efficiency. Notably, people living in poorer households are less likely to invest in energy efficiency and may end up using a high share of their income to pay for electricity. This is referred to as energy poverty in the literature. Unexpectedly, income has no significant effect on the adoption of renewable energy technologies. This can be explained by the existence of various financial supports among OECD countries to promote renewable energy. There is evidence of split incentives regarding decisions to invest in energy efficiency and to invest in renewable energy. The fact that a household owns a residence increases its probability of undertaking investments in energy efficiency and in renewable energy. Regarding dwelling characteristics, we find that the type of dwelling and its size have a significant effect on the decision to invest in energy efficiency and no effect on the decision to adopt renewable energy. Also, environmental motivations and commitment have mixed effects on both investment in energy efficiency and adoption of renewable energy. Trust in researchers, scientists and experts has a positive effect on the two decisions.

Fourth, regarding the joint adoption, we find that the influence of income becomes less important in the decision of the household to go further when it has undertaken any of these investments. We also find that tenants are less likely to combine the two investments due to split incentives. Also, a household that has already undertaken one of the investments and is living in a detached dwelling is more likely to make additional efforts to invest in the second, while size of the residence has no significant effect. This limitation can be overcome by environmental motivations. In this sense, people who have already undertaken one of the investments and for whom environmental issues are generally more important than non-environmental issues, are more likely to have an additional motivation to address barriers that could prevent them from fully contributing to the energy transition. Also, participation in charitable, environmental and local organizations has a positive effect on the joint adoption, as does trust in scientists and local authorities.

The remainder of the paper is structured as follows. In section 2, we provide an empirical literature review on both adoption of renewable energy and investment in energy efficiency. In section 3, we present the theoretical predictions of relationships between the two decisions. Section 4 is devoted to the empirical analysis. We conclude in section 5.

2. LITERATURE REVIEW

There is considerable literature on either demand for clean energy or investment in energy efficiency in the residential sector. In section 2.1, we provide some important studies on demand for clean energy and household behavior while section 2.2 provides some analysis on household behavior and the decision to invest in energy efficiency. To our knowledge, there is no specific investigation of the simultaneous decisions of renewable energy adoption and investment in energy efficiency at the household level. As the two decisions to adopt renewable energy and to invest in energy efficiency are taken by the same household in the residential sector and both are important in a transition to a green economy, an analysis of a joint decisions needs particular attention.

2.1 Clean energy demand and household behavior

There is noteworthy literature on the demand for green energy, due to the importance of energy in the CO_2 emissions that bring about climate change. Notably, in the residential sector, studies primarily focus on real behavior or hypothetical behavior to explain the decision of the household regarding renewable energy. However, the two approaches often give different results (Cameron et al., 2002; Kotchen and Moore, 2007; Poe et al., 2002). The hypothetical behavior based on stated-preference methods can rely on the willingness to adopt renewable energy(Gerpott and Mahmudova, 2010; Ozaki, 2011; Zhai and Williams, 2012 and Sardianou and Genoudi, 2013), on the willingness to pay for renewable energy (Ek and Söderholm, 2008; Bollino, 2009; Zorić and Hrovatin, 2012 and Liu et al., 2013.) or on both decisions (Krishnamurthy and Kriström, 2014; and Shi et al., 2013).

Gerpott and Mahmudova (2010) find that environmental attitudes and social environment have a strong influence on the consumer and their propensity to adopt green electricity. On the contrary, Ozaki (2011) uses correlation analysis and finds that pro-environmental consumers do not necessarily adopt green electricity. A lack of strong social norms and personal relevance affect the adoption of renewable energy, as well as the value of the renewable energy (benefits and costs). In addition to environmental concern, Zhai and Williams (2012) investigate the influence of social acceptance, and show in a specific case of photovoltaics (PV) adoption that social acceptance also affects the adoption of renewable energy. Financial incentives through taxes or subsidies are also important to promote adoption of clean energy. Sardianou and Genoudi (2013) find that in Greece, a tax deduction is the most effective financial policy measure to promote consumer acceptance of renewable energy in the residential sector.

Many studies consider the willingness to pay for renewable energy. Ek and Söderholm (2008) investigate norm-motivated and economic-motivated behavior in the Swedish green electricity market. They find that variables such as cost of adoption, personal responsibility, perception of the benefit of adoption and social norms to be the most important determinants of households choosing to pay a price premium for green electricity. Zorić and Hrovatin (2012) suggest that awareness-raising campaigns should follow green marketing, which should target younger, well-educated and high-income households. In a specific case of developing countries, Liu et al. (2013) investigate rural social acceptance of renewable energy adoption and find that rural residents are generally favorable to renewable electricity development given its positive impact on the environment. Krishnamurthy and Kriström (2014) and Shi et al. (2013) focus on the willingness to accept and the willingness to pay to use only renewable energy and their disparities across OECD countries. The former uses the 2011 EPIC-OECD survey while the latter uses the 2007 EPIC-OECD survey. Krishnamurthy and Kriström (2014) find a low willingness to pay (WTP) that corresponds to 11–12% of the current electric bill and income having an ambiguous effect. In the same way, Shi et al. (2013) find that economic variables are less important, while environmental concern or attitude consistently drives the decision to enter the hypothetical market of green electricity. They also find that participation in environmental organizations has significant effects on the WTP to use only renewable energy.

There are fewer studies in the literature investigating the actual behavior of consumers regarding renewable energy adoption, relying on real surveys instead of hypothetical consumer behavior. A survey that relies on the real behavior of consumers can help investigate how consumers actually react according to different financing mechanisms for green electricity. Roe et al. (2001) find that hypothetical analysis based on the WTP and hedonic analysis of actual price premiums charged for green electricity give similar values for key environmental attributes. Some studies only focus on green consumers (Young et al., 2010) and can suffer from selection bias, because policy recommendations could not be extended to consumers who do not adopt green behaviors. There are also disparities in the effect of different financing mechanisms for green electricity. For example, Kotchen and Moore (2007) consider a voluntary contribution mechanism (VCM) and a green tariff mechanism (GTM) to finance new generation capacity. They find that the two financing mechanisms are not equivalent when the constraint related to the level of contribution is binding. Arkesteijn and Oerlemans (2005) investigate factors that influence the early adoption of green electricity by Dutch residential users combining cognitive and economic approaches. They find that in addition to economic variables; cognitive variables and those related to basic knowledge and to actual environmental behavior in the past strongly predict the probability of early adoption of green electricity.

Variables that affect green demand in the residential sector may also affect a household's decision to invest in energy efficiency. In the following section we describe some literature on factors influencing energy efficiency investment decisions in the residential sector.

2.2 Energy efficiency and household behavior

There is a substantial literature on household behavior and its effect on adoption of and investment in energy efficiency. Energy efficiency is a relatively cheap way to reduce GHG emissions in the short and medium term (Dietz et al., 2009; and Vandenbergh et al., 2007), while in the long term a complete transition to a low carbon economy is likely to be very slow (Fouquet, 2010). There is a large amount of evidence that economic factors motivate energy efficiency (Howarth, 1997; Kempton and Neiman, 1986 and Steg, 2008) and can be helpful in designing appropriate taxes or subsidy mechanisms to promote energy saving. For example, saving money or energy bill reductions can be incentives to invest in energy efficiency. However, the potential gain from reducing energy use can be hindered by some problems such as split incentives, uncertainty about the gain, and the moral hazard problem that may prevent households from adopting or investing in an energy conservation system (Gillingham et al., 2012 and Alberini et al., 2013). Reducing energy use can also lead to reverse effects such as the rebound effect or the take-back effect (Greening et al., 2000 and Turner, 2013). The rebound effect can be solved by capturing efficiency gains for reinvestment in natural capital rehabilitation (Wackernagel and Rees, 1997) or in supporting environmental actions through donations (Bindewald, 2013). The rebound effect can also be solved by pro-environmental motivation (Urban and Ščasný, 2012).

However, in the literature on energy-saving behavior, there is no evidence of the effect of pro-environmental motivation on energy-saving actions at household level. The early literature found that environmental concern does not have any effect on either energy consumption or energy-saving actions (Heslop et al., 1981). On the other hand, there has been a growing concern about climate change in recent years (Capstick et al., 2015) and many recent studies find that environmental concerns have a significant effect of on energy-saving actions (Barr et al., 2005; and Whitmarsh and O'Neill, 2010). A few studies still find that pro-environmental motivation has a limited effect (Carlsson-Kanyama et al., 2005; and Whillans and Dunn, 2015) or no effect (Steg, 2008). Also, both economic and environmental concerns have different effects when we distinguish the actions of investing in energy efficiency.

The two main types of energy conservation actions are efficiency investment and curtailments (Jansson et al., 2009). The former involves the acquisition of new technologies, low-energy appliances (top-rated energy-efficient appliances, low-energy light bulbs, energy-efficient windows, etc.) or energy efficient systems (automated control systems, domotics or home automation), that require monetary investment. The latter refers to non-monetary investments in behavior change such as scheduling, turning off lights, cutting down on heating or air conditioning and switching off standby mode. For example monetary efficiency investments that rely on external conditions (Urban and Ščasný, 2012) such as economic concerns, are less affected by internal motivations (Guagnano et al., 1995) such as pro-environmental motivations. Black et al. (1985) find the opposite effect on non-monetary efficiency investments. In the end, both economic and environmental concerns may have significant effects on energy-saving actions which are the outcome of both monetary and non-monetary investments. In addition to socio-economic and demographic factors, (Urban and Ščasný, 2012) investigate how environmental concern affects the adoption of monetary and non-monetary investments in energy efficiency in a multi-country setting using EPIC-OECD data. They find a positive and significant effect for pro-environmental motivation and a mixed effect for the other variables.

The different variables that affect household decisions about renewable energy adoption may have significant effects on energy efficiency investments as well. The fact that studies mostly focus on either renewable energy adoption or energy efficiency investment may explain empirical disparities in the effect of economic and environmental concerns. Interestingly enough, if the two decisions are interrelated due to unobserved characteristics that determine the two decisions, an analysis of the joint decision of adoptions would be more appropriate. For example, a household that is pro-environmental can find it necessary to also invest in renewable energy (resp. in energy efficiency) if it has already invested in energy efficiency (resp. renewable energy). In this case, the household may rely on its environmental conscientiousness to combine the two investments. In the same way, a household that already invests in energy efficiency (resp. renewable energy) may have limited financial capacity to also invest in renewable energy (resp energy efficiency). Therefore, by jointly analyzing the two possible decisions taken by the household on the adoption of renewable energy and investment in energy efficiency, one can capture the possible relationships between them. Such analysis holds potential for policy formulation, as adoption of renewable energy and investments in energy efficiency are both important in the future world energy market (Sheffield, 1997) and in the energy transition. To our knowledge, there is no such investigation in the economics literature and our study aims to fill this gap.

3. THEORETICAL PREDICTIONS OF RELATIONSHIPS BETWEEN THE TWO DECISIONS

In the following section, we develop a simple model to explore the possible relationships between the two decisions about investing in energy efficiency and in renewable energy at household level.

3.1 The model

As in Ekholm et al. (2010), let us assume that the consumption of energy can be separated from other consumption to form its own consumption problem, i.e. that the utility from energy is separable from other sources of utility and that the consumer has a specific energy budget which we denote R. This energy budget can be seen as the income that a household devotes to energy problems. It can also include a financial support or a "green grant" such as subsidies, government tax credits or interest-free eco-loans from a bank, that targets energy efficiency and renewable energy adoption.[1] We assume that a household devotes this energy budget to buy energy and also to undertake investments in energy efficiency and in renewable energy, which contribute to a transition to a low carbon economy.

During the first period ($t=0$) investments in energy efficiency ee and in renewable energy re are undertaken at a cost k_1 and k_2 respectively. The rest of the energy budget is devoted to buy an amount d of energy provided from non-clean sources of energy at each period of time. We normalize the discounted unit price of this energy to one so that k_1 and k_2 can be interpreted as relative costs. Following Zhai and Williams (2012), we assume that the unit cost of investment in renewable energy is higher than the unit price of non-clean energy (i.e. $1-k_2<0$). The energy budget constraint of the household can be written as:

$$R = D + k_1 ee + k_2 re, \tag{1}$$

where $D=\sum_{t=0}^{p} d_t = d_t + d_{-t}$ is the total amount of non-clean energy over the whole period of time and d_{-t} is the amount of non-clean energy for the whole period except period t.

For simplicity and to conform to cross-sectional data, we do not consider temporal effects of investments in energy efficiency and in renewable energy. Instead, we assume that the levels of the two investments are chosen at the first period. Therefore, we refrain from time-indexing the variables in the rest of the model. The energy budget constraint (1) expresses the limited investment capacity of the household. In fact, investment in energy efficiency is negatively related to investment in renewable energy for a given energy budget. This limited investment capacity may not favor a joint investment in both renewable energy and energy efficiency.

The household gets some satisfaction $u(E_s)$ from using energy services E_s for fundamental needs such as cooking, lighting, electric home appliances, etc. We denote by E, the total amount of energy sources, which is the sum of the clean energy (re) and the non-clean energy (d). The utility function $u(.)$ is assumed to be increasing and concave ($u'>0$ and $u''<0$). For simplicity, we assume that the two sources of electricity are perfect substitutes and that the utility function u exhibits constant elasticity of intertemporal substitution ε less than unity ($\varepsilon \le 1$). Following Charlier et al. (2011), we assume that a household invests in energy efficiency in order to lower the cost of the energy in the future. Investing in energy efficiency helps the household to save energy during the following periods and therefore to enjoy energy services at a lower cost. In this sense, the level of the clean energy service and that of the non-clean energy service depends on the level of investment in energy efficiency (ee). Furthermore, we define $\alpha(ee)$ as the energy efficiency parameter such that the amount of energy sources E that is required for a given energy service E_s, depends negatively

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[1] In order to promote greener purchasing decisions, several countries have implemented policies providing financial support to households. According to OECD (2014) report, the Canadian ecoEnergy Retrofit-Homes program helps home-owners to invest in energy-efficient upgrades such as insulation, upgrades or replacement of heating and cooling systems. Financial incentives such as tax credits or interest-free eco-loans are available in France as well to promote energy efficiency investments in the residential sector and investment in renewable energy.

on $\alpha(ee)$ which is assumed increasing and concave: $E_s = \alpha(ee)E$. The more the household invests in energy efficiency, the less it requires renewable energy and non-clean energy to get the same energy services. Even though a large number of papers (Greening et al., 2000 and Turner, 2013 for example) show that the potential gain from investing in energy efficiency can be hindered by energy rebound effect or the take-back effect, some studies find a solution to avoid this reverse effect (Wackernagel and Rees, 1997, Bindewald, 2013 and Urban and Ščasný, 2012). Consequently, we assume that these solutions are implemented so that the household cannot have such adverse behavior.

In addition to personal or direct gain, investments in energy efficiency and in renewable energy help protect the environment by reducing global CO_2 emissions. Hence, a household achieves additional environment-related satisfaction by investing in energy efficiency and renewable energy. Doni and Ricchiuti (2013) consider the sensitivity of consumers toward environmental improvements to be dependent on their degree of environmental awareness. Zhang et al. (2015) and Liu et al. (2012) explicitly model this sensitivity as consumer environmental awareness. This formulation is also close to that of a study by Ekholm et al. (2010) which consider that the consumer also gets some disutility from consuming an inconvenient fuel. As investments in energy efficiency and in renewable energy positively contribute to reductions in global CO_2 emissions, the consumer gets some additional satisfaction by undertaking the two investments, depending on their pro-environmental motivation.

In the same vein, we assume that the household gets additional environment-related satisfaction $v(re, ee)$, which captures the positive joint effect of the two decisions. The positive joint effect can be interpreted as follows. Consider that the household's environmental satisfaction comes from his ability to completely self-source its electricity needs. A pro-environment household can then take advantages on the synergy between energy efficient and renewable energy technologies to fully rely on renewable energy. In this sense, energy efficient technologies reduce the overall electricity demand such that the available quantity of renewable energy is sufficient to satisfy its electricity demand (for example, a net zero energy building). The additional environment-related satisfaction exhibits the following characteristics:

$$\frac{\partial v}{\partial re} > 0, \frac{\partial v}{\partial ee} > 0, \frac{\partial^2 v}{\partial ee \partial re} = \frac{\partial^2 v}{\partial re \partial ee} > 0 \ \ and \ \ \frac{\partial^2 v}{\partial re \partial re} = \frac{\partial^2 v}{\partial ee \partial ee} = 0.$$

The joint effect is defined as the cross derivative of the utility $v(re, ee)$. The marginal utility of investing in renewable energy (resp. energy efficiency) rises with investment in energy efficiency (resp. renewable energy). Therefore, this additional utility is high for the environmentally-friendly household that takes both decisions.

Investments in energy efficiency and in renewable energy last for a finite horizon of time.[2] Thus, the consumer cannot benefit infinitely from the two investments. We assume that the future gains from investment in energy efficiency and renewable energy are limited to p periods. The gross instantaneous utility of the household can be defined as:

$$U(ee, re, d) = u\left[\alpha(ee)re + \alpha(ee)d\right] + v\left(re, ee\right). \tag{2}$$

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[2] Major renovations or refurbishment of residential buildings occur at 30–40 year intervals (Laustsen, 2008), while photovoltaic modules are usually guaranteed for a lifetime of 25 years (OECD/IEA, 2014).

3.2 Optimal allocation

The household maximizes the discounted sum of instantaneous utilities defined in eq.2 subject to the energy budget constraint eq.1 with respect to consumption of non-clean energy (*d*), investment in energy efficiency *ee* and investment in renewable energy *re* as follows:

$$\begin{aligned} &\max_{d,ee,re} \sum_{t=0}^{p} \beta^t U\left(ee, re, d\right), \\ &st \quad R = d_t + d_{-t} + k_1 ee + k_2 re \end{aligned} \tag{3}$$

where β is the discount factor. By replacing *d* from eq.1 into the objective function of the program (3), the first order conditions with respect to *ee* and *re* give respectively:

$$\alpha'(ee)u're + \alpha'(ee)u'd + \frac{\partial v}{\partial ee} = k_1 \alpha(ee)u' \tag{4}$$

and

$$\frac{\partial v}{\partial re} + \alpha(ee)u' = \alpha(ee)k_2 u' \tag{5}$$

Equations (4) and (5) are equilibrium conditions. Equation (4) states that the marginal gain of investing in energy efficiency should be equal to its opportunity cost, which is the marginal forgone utility. The marginal gain of investing in energy efficiency has two components: a direct marginal utility due to the amount of energy sources that is saved ($\alpha'(ee)u're + \alpha'(ee)u'd$) and a marginal environment-related satisfaction $\left(\frac{\partial v}{\partial ee}\right)$. The opportunity cost is the direct marginal forgone utility ($k_1\alpha(ee)u'$). Similarly, equation (5) states that the marginal gain of investing in renewable energy $\left(\frac{\partial v}{\partial re} + \alpha(ee)u'\right)$ should be compensated with the corresponding opportunity cost ($\alpha(ee)k_2u'$).

Putting equation (5) into equation (4), gives the following equation that defines the household optimal allocation of investments in energy efficiency and in renewable energy:

$$\alpha'(ee)u'(re + d) + \frac{\partial v}{\partial ee} = \frac{k_1}{k_2 - 1}\frac{\partial v}{\partial re}. \tag{6}$$

Equation (6) states that at the optimum, the marginal benefit of investing in energy efficiency is equal to the marginal environment-related satisfaction of investing in renewable energy adjusted by a factor that depends positively on the unit cost of investment in energy efficiency (i.e. k_1) and negatively on the unit cost of investment in renewable energy (i.e. k_2). In order to determine if the two decisions are substitutes or complements, we focus on the effect of investment in renewable energy on investment in energy efficiency.[3] Primarily, we analyze the sign of the total derivative of investment in energy efficiency with respect to investment in renewable energy $\left(\frac{dee}{dre}\right)$. A positive sign means that an increase in the investment in renewable energy will increase investment in energy efficiency so that the two decisions are substitutes.

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[3] The definition of complementarity and substitutability in this paper is based on the direct effect because we aim to analyze the relationships between the two decisions of a household facing an energy budget constraint and costly investments in energy efficiency and in renewable energy. There are other complementary vs substitutability concepts such, price cross-elasticity, Fisher perfect complementarity, Edgeworth-Pareto complementarity (Samuelson, 1974).

Proposition 1*: There is a threshold on the joint effect below (resp. above) which investment decisions in energy efficiency and in renewable energy of the household are substitutes (resp. complements).*

The proof of proposition 1 is provided in appendix A. The threshold level of the joint effect is given by:

$$\overline{v_{eere}} = \frac{1-k_2}{k_1}\left[k_1\alpha' u' - \alpha'' u'(re+d) - \frac{\alpha'^2}{\varepsilon\alpha}\frac{\partial v}{\partial ee} \right].$$

After investment in renewable energy has been undertaken, the household will additionally invest in energy efficiency if the cross effect $\frac{\partial^2 v}{\partial ee \partial re}$ is higher than the threshold $\overline{v_{eere}}$. This can be explained by the fact that a less environmentally-friendly household is looking more for energy saving in order to reduce its energy bill than to contributing to a reduction in global emissions of CO_2, while a more environmentally-friendly household is getting additional satisfaction from protecting the environment. This result is consistent with the reasoning in Sun and Yang (2006): the household behaves as though it has two decisions *ee* and *re* which are divided into two different sets S_2 and S_1 depending on their function. S_1 refers to energy saving or economic motives while S_2 refers to environmental protection motives. Decisions in the same set are substitutes and decisions across the two sets are complements. In the same vein, the decisions of a household with a low pro-environmental index are mostly for economic motives (S_1) and are then substitutes. Whereas the decisions of a more environmentally-friendly household are complements, because they are guided by both economic and high environmental motivations (S_1 and S_2).

We have theoretically shown that there exists a relationship between the decisions of the household to adopt renewable energy and energy efficient technologies. In Section 4, we conduct an empirical analysis using a survey data from OECD countries. We primarily focus on the relationship between the household decisions to adopt energy efficient and renewable energy technologies. We use a bivariate probit (biprobit) model to explore whether the decisions to adopt renewable energy and to invest in energy efficiency in the residential sector are related. Furthermore, we empirically investigate the existence of a threshold on the cross effect as Proposition 1 shows. We estimate the biprobit model across different types of pro-environment households based on the variable related to environmental concerns. We also analyze the differential impact of the factors across the two decisions using the results from the biprobit estimation. Additionally, we investigate the determinants of the joint adoption of energy efficient and renewable energy technologies by computing a joint probability of adoption from the results of the biprobit model. Basically, we intend to explain why some households decide to invest both in energy efficiency and in renewable energy, while others decide to only invest in renewable energy or to only invest in energy efficiency, or to do nothing. The household that only adopts renewable energy or only reduces its energy consumption, contributes to the energy transition better than the household who does nothing, and less than the one who undertakes the two investments. As the data does not provide information on the level of investment, we rather consider the adoption decision of the household regarding renewable energy and energy efficiency. Moreover, as the survey is based on self-reporting, we are not able to observe the cross-effect corresponding to true environment-related satisfaction. Thus, we assume that the cross-effect is part of the unobserved characteristics of the household. Moreover, information about the energy budget of the household were not provided. Alternatively, we consider the income as a proxy and examine its effect on the two decisions. Finally, we control for other characteristics of the household that can affect its decisions, which are not considered in the theoretical model. Those control variables are characteristics of the residence, environmental attitudes, perceptions, etc.

4. EMPIRICAL ANALYSIS

In this section, we first present the data and methods used (Section 4.1). Second, we present the bivariate probit model (biprobit) to empirically investigate the relationship between the decisions of renewable energy adoption and of the adoption of energy efficient technologies (Section 4.2). Third, we focus on factors explaining the two adoption decisions (Section 4.3). Finally, we analyze the determinants of the joint adoption (Section 4.4).

4.1 Data and Methods

4.1.1 Data

We use the first two rounds of the large-scale household survey on Environmental Policy and Individual Behavior Change (EPIC) conducted by the Organization for Economic Cooperation and Development (OECD). The two rounds focus on five thematic areas (energy, food, transport, waste and water) and aim at understanding household reactions to different environmental policies, the interactions of these policies and the role of household attitudes towards the environment (Serret and Brown, 2014). Information was collected on household characteristics (age, income, education), environmental attitudes (environmental concerns), and perceptions, etc., using an internet-based questionnaire.

The first round of the EPIC survey was carried out in January-February 2008 in ten OECD countries (Australia, Canada, France, Korea, Netherlands, Sweden, Czech Republic, Italy, Norway and Mexico.). The sample size was approximately 1,000 households in each country for a total of 10,251 households. In 2011, the same survey was carried out in the first six countries from 2008 and in five additional countries (Chile, Japan, Spain, Israel and Switzerland.). As in the first round, approximately 1,000 households were interviewed in each country for a total of 12,202 households. The sample size for the two rounds is 22,453 households. The dataset of the 2011 EPIC survey is richer than that of 2008 because it includes additional areas such as eco-innovation, knowledge, policy preferences and country-specific questions. Unfortunately, we could not use this additional information because we intend to use the two datasets to account for time variation. Therefore, we need to use the same type of information (variables) for household behavior across the two survey rounds. As the same respondents cannot be identified in the EPIC survey from 2008 to 2011, we decide to pool the two datasets for the fifteen countries and to control for the effect of year. Note that efforts were made to avoid sample bias through stratification (age, gender, etc.) and quota sampling with large geographical coverage.[4] Also, the two rounds are independent surveys and each represents a random sample from the population. Then, there is no correlation in the error terms within the observations of each survey.

We use data from the energy section (Part E) of the EPIC survey which we combine with socio-demographic characteristics (Part A), and attitudinal characteristics (Part B). Specifically, in the energy section we mainly focus on questions that concern the adoption of renewable energy (solar panels, wind turbines, hydro, etc.) and monetary investments in energy efficiency (Energy-efficiency-rated appliances, low-energy light bulbs, etc.). For a robustness check, we additionally

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[4] For more details, see OECD (2011, 2014).

consider non-monetary investments (switch off lights when leaving a room, cut down on heating or air conditioning, switch off appliances when not in use, switch off standby mode of appliances or electronic devices, etc.) that help reduce the consumption of energy as well. Both independent and dependent variables used in this paper are described in the following section (section 4.1.2).

4.1.2 Description of variables

Following the theoretical model, the dependent variables are related to investments in renewable energy and energy efficiency. As the data does not provide information on the level of investments, we consider the decisions of the household to adopt renewable energy or to invest in energy efficiency. These two dependent variables are then constructed from questions related to renewable energy adoption and investments in energy efficiency. In the two survey rounds, a question was asked to identify households that installed renewable energy equipment in their current primary residence (solar panels for electricity or hot water and wind turbines) over the past ten years. Households could answer that they installed renewable energy items or that the residence was already equipped. As we are focusing on the decision to adopt renewable energy, we do not consider households whose residence was already equipped. We cross the information on the installation of renewable energy items with the source of electricity that the residence uses.

We also consider households stating that energy from the electricity provider is already from renewable energy sources (EPIC 2008) or that they have chosen the "renewable or green" energy tariff from their electricity provider (EPIC 2011), adopted renewable energy. Additionally, the 2011 survey provides a refinement giving some information on households using thermal solar panels for water heating, who are also considered as having adopted renewable energy. Although the investment decision in renewable energy and the decision to sign a contract with the electricity provider for a "renewable or green energy tariff" are fundamentally different, the two decisions can be interpreted as the decision to adopt renewable energy. To account for the fact that the two decisions are different, that is, the former decision requires financial investment and is irreversible while the latter decision is an electricity grid agreement which does not necessitate large investments and is reversible, we perform a robustness test that considers only investment decision in renewable energy (see Table 7).

The EPIC surveys provide information on monetary investment in energy efficiency such as: top-rated energy-efficient appliances, low-energy light bulbs, energy-efficient windows, thermal insulation of walls or roof, etc.). Households were asked whether or not they installed energy efficiency items over the past ten years in their current primary residence. As before, we only consider self-installed items as adoption of energy efficiency items to reduce the use of energy and not items that had already been installed. The EPIC surveys also provide information on behavior changes to reduce the use of energy, that we call non-monetary investments in energy efficiency. Households were asked how often they adopt behaviors that could help reduce their energy use in their daily life, such as: cutting down on heating or air conditioning, switching off standby mode of appliances or electronic devices (TV, computer), air dry laundry rather than using a clothes dryer, etc. For a robustness check, we later include non-monetary investments in energy efficiency which we combine with monetary investments in energy efficiency. Whether the household invests in energy efficiency by using a part of its income or makes efforts to reduce its consumption of energy towards behavior change, in the end the household reduces its consumption of energy.

Though the theoretical model does not include many household characteristics, we decide to control for them as they can also influence the decisions of households. However, there is no evidence in the literature about the importance of either socio-economic and residential variables or attitudinal and perception variables in the decision of a household to adopt renewable energy or to invest in energy efficiency. Therefore, we include some variables that are available in the two EPIC datasets and can also be useful for policy recommendations in our independent variables. We consider three categories of characteristics. First, we use socio-economic and residential variables such as gender, age, household income, characteristics of the residence, etc. The size of the residence and the type of residence (detached or multi-occupancy) are used as proxies for the characteristics of the residence. Second, we consider perception, voting in elections, trust in and commitment to any local, charitable or environmental organization as attitudinal variables. Third, some variables are also related to energy use: individual metering, peak price of electricity, factors that encourage reduction of energy consumption, etc. Note that we do not consider the energy consumption because it would necessitate that we control for different climate conditions (see for example Zhao and Magoulès, 2012). Collecting the weather data at the city level for all the countries that were included in the OECD-EPIC survey would be very challenging. Finally, we control for the year. The full description of the independent variables that are used and the summary statistics are presented in appendix C (table 14).

4.1.3 Methods

The household faces two different decisions that contribute to energy transition. It can decide whether or not to invest in renewable energy. It can also decide whether or not to invest in energy efficiency. The household has two decisions that could be related, as shown in the proposition 1 of the theoretical model. As the survey was based on self-reporting, we are not able to observe the cross-effect corresponding to true environment-related satisfaction. The cross-effect is therefore assumed to be a part of the unobserved characteristics of the household. Although the two decisions do not directly depend on each other, their error terms may be correlated through unobserved characteristics. Following Cameron and Trivedi (2010), we first use a bivariate probit model that accounts for the joint decisions based on their correlation. Note that the probit model assumes that unobservable variables and residuals are normally distributed and independent of the explanatory variables. The general specification of the model is:

$$re^{*} = X^{'}\beta_1 + \varepsilon_1 \tag{7}$$

and

$$ee^{*} = X^{'}\beta_2 + \varepsilon_2, \tag{8}$$

where re^{*} and ee^{*} are latent variables (resp. investment in renewable energy and investment in energy efficiency), which determine the observed binary outcomes *re* (decision to adopt a renewable energy) and *ee* (decision to invest in an energy efficiency) such that $j = 1$ if $j^{*} > 0$ and $j = 0$ otherwise, with $j \in \{ee, re\}$. X denotes the vector of regressors (economic and residential variables, variables of perception, commitment and trust, energy use, etc.) that determine both re^{*} and ee^{*}. Moreover, the error terms ε_1 and ε_2 are assumed to be jointly normally distributed with means 0 and variances of 1. In order to account for unobservable factors that may jointly motivate the two decisions, we allow for some correlation (ρ) between ε_1 and ε_2.

Additionally, we focus on factors that affect the joint probability of adopting renewable energy and investing in energy efficiency. In fact, we intend to explain why some households decide to invest both in energy efficiency and in renewable energy, while others decide to only invest in re-

Table 1: Investment in energy efficiency by adoption of renewable energy

	Adoption of renewable energy (RE)		
Investment in energy efficiency (EE)	no	yes	Total
no	1,967	551	2,518
yes	10,423	5,878	16,301
Total	12,390	6,429	18,819

Table 2: Cross-correlation and tetrachoric correlation

Variables	Adoption of renewable energy	Investment in energy efficiency
Adoption of RE	1.000	
Investment in EE	0.1018 (0.0000)	1.000
Tetrachoric correlation	0.2188 (0.000)	

()=significance level.

newable energy or to only invest in energy efficiency or to do nothing. Therefore, the household that only adopts renewable energy or only reduces its energy consumption (i.e. $re = 1$ and $ee = 0$ or $re = 0$ and $ee = 1$) contributes more to the energy transition than the household who does nothing (i.e. $re = 0$ and $ee = 0$) and less than the one who undertakes the two investments (i.e. $re = 1$ and $ee = 1$) . To account for the joint adoption, we compute the joint probability from the results of the biprobit model. Note that alternative models such as ordered or multinomial logit or probit give quite similar results.

4.2 Empirical investigation of the relationships between the two decisions

Table 1 displays the cross repartition of the two decisions of renewable adoption and investment in energy efficiency.

According to Table 1, the majority of households in the sample (87%), invest in energy efficiency. Then, a large majority of households undertake monetary investments in energy efficiency. On the contrary, only 34% adopt renewable energy by installing their own solar panels or wind turbines, or by subscribing to green energy from the electricity provider. Cross analysis shows that among those who invest in energy efficiency, only 36.06% of households additionally adopt renewable. Another 10.45% of households decide neither to adopt renewable energy, nor to invest in energy efficiency. Finally, very few households in the sample (3%) adopt renewable energy without investing in energy efficiency. So, there are good reasons to believe that the two decisions may be correlated. To verify this, we provide the cross-correlation and the tetrachoric correlation[5] between the decision to adopt renewable energy and that of investing in energy efficiency.

The two correlation coefficients of 0.1018 and 0.2188 are positive and different from zero (Table 2). Following Cameron and Trivedi (2010), we use a bivariate probit model that accounts for the joint decisions based on their correlation. First, we check whether the bivariate probit model is necessary. The result from the bivariate probit provides the test of the null hypothesis that the true correlation coefficient is equal to 0 and justifies the importance of using the bivariate probit model instead of estimating the two decisions separately. Our results reject the null hypothesis of the correlation coefficient at 1% (Prob>chi2=0.0000). Therefore, the bivariate probit model is more

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[5] Note that the tetrachoric correlation is more appropriate because the two variables (RE and EE) are binary.

Table 3: Comparison of predicted probabilities with sample frequencies

Variable	Mean of Prob	Frequency
RE=1	0.40	0.34
EE=1	0.89	0.87
RE=0 and EE=0	0.08	0.11
RE=0 and EE=1	0.51	0.56
RE=1 and EE=0	0.03	0.02
RE=1 and EE=1	0.38	0.31

Table 4: Coefficients of correlation between RE and EE across environmental concern

Environmental concern	Coefficient of correlation
1	0.2572 (0.0001)
2	0.2054 (0.0007)
3	0.1813 (0.0008)
4	0.1702 (0.0049)
5	0.1512 (0.0058)
6	0.1351 (0.0256)
All	0.1660 (0.0000)

()=significance level.

appropriate than separate univariate probit models because the two decisions are interrelated due to unobserved characteristics that jointly determine the two decisions. Additionally, we perform the Wald test. The Wald statistic gives 47.7635 and also rejects the null hypothesis of the correlation coefficient at 1% (Prob>chi2=0.0000).[6]

Second, we perform goodness of fit and prediction tests in order to evaluate how well the model fits the observations. The goodness of fit test consists in comparing the predicted probabilities from the bivariate probit model with the corresponding sample frequencies (see Table 3). We find that the predicted probability is close to the frequency of the sample. For the prediction test, we compute the percentage of correctly classified observations. More specifically, we compare predicted outcomes with actual outcomes and find that the percentage of correctly specified values, also referred to as the rate of prediction, is high (53.22 %). We can then conclude that overall, the bivariate probit model fits well the observations.

Furthermore, we empirically investigate the existence of a threshold on the cross effect as Proposition 1 shows. We estimate the biprobit model across different types of pro-environment households based on the variable related to environmental concerns. Table 4 summarizes the coefficient of correlation from this estimation of the biprobit model. The table shows that for all the groups of households, there is a positive interrelation between the two decisions due to unobserved characteristics that jointly determine the two decisions. This positive interrelation conforms to the complementarity relationship in the theory section. In this case, the two decisions of a more environmentally-friendly household are complements. Also note that, the correlation between the two decisions is higher and more significant when household gives more priority to environmental is-

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[6] Note that we use the pseudo-maximum likelihood method to account for robust standard errors. Consequently, standard likelihood ratio tests are no longer valid.

sues. The non-existence of the substitution relationship with negative interrelation between the two decisions can be explained by a very low threshold on the cross effect under which there is substitution. Another explanation can be that households overestimate their environmental concern in their declaration. In this sense, it is more appropriate to consider that the true environmental motivations are part of the unobserved characteristics.

The results show that there is a positive interrelation[7] between the decision of the household to invest in energy efficiency and to adopt renewable energy, due to unobserved characteristics such as environmental motivations. In fact, motivations are derived from self-reporting in which they were asked to rank the importance of many types of problems, including environmental issues. As a consequence, the true environmental motivation and the corresponding cross effect are not observed, and may lead to such a positive correlation. In this sense, a more pro-environmental household is more likely to invest in energy efficiency and in renewable energy.

4.3 Factors explaining the adoption of renewable and the adoption of energy efficient technologies

We can now turn to the interpretation of the results of the bivariate probit model which focuses on the residential characteristics, the economic and environmental motivations, split incentive issues and perceptions, that can help in understanding the energy transition decisions of households.

Energy poverty

Household income has a positive and significant effect on the decision to invest in energy efficiency, while there is no significant effect on the decision to adopt renewable energy. People living in wealthier households are more likely to invest in energy efficiency, as found in Urban and Ščasný (2012). As investments in energy efficiency such as home renovation and energy saving technologies are costly, a high income household has a greater financial capacity to afford them and to benefit from reduction in their energy bill. So, people living in poorer households may end up using a large share of their income to pay for electricity, which is referred to as energy poverty (Bird and Hernández, 2012).Unexpectedly, income has no significant effect on the adoption of renewable energy in some countries as found in Shi et al. (2013), which is not consistent with the results in Zorić and Hrovatin (2012). This can be explained by the existence of various financial supports in some countries to promote renewable energy. On the other hand, financial supports for energy efficiency mainly target home renovation and are less directed at energy-efficient appliances or low-energy light bulbs for example. Additionally, households benefit from policy mechanisms such as feed-in tariffs, which allow them to sell their renewable energy at a guaranteed price, determined as closely as possible to the specific generation costs (Couture and Gagnon, 2010).This may give them an additional incentive to invest in renewable energy. Also, it is possible to buy green electricity directly from the electricity provider which may be profitable in the short term, and which could help households avoid costly investment to produce their own renewable energy. An interesting implication of the income effect is that investment in energy efficiency merits specific financial supports.

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[7] Note that the term "interrelation" is alternatively used with the term "correlation" to mean that the two decisions are related.

Split incentives

Ownership positively affects the adoption of renewable and investment in energy efficiency. The fact that a household owns a residence increases its probability of undertaking investments in energy efficiency and in renewable energy. This is logical in the sense that investment in renewable energy generation such as solar panels or wind turbines and in home renovation is mostly profitable after many years of use (30–40 years for home renovations and 25 years for photovoltaic modules). Such investments are therefore risky in the case of limited tenure. Although it is possible to move solar or wind installations, dismantling and re-installation are costly and may be very problematic. Therefore, without security of tenure a tenant will have less incentive to invest in renewable energy. This is commonly referred to as the 'split incentive' in the literature (Bird and Hernández, 2012 and Gillingham et al., 2012), and is a barrier to energy efficiency. Our results are novel as they also show the presence of this barrier to renewable energy adoption.

Effects of dwelling characteristics

We find that the type of dwelling and its size have a significant effect on the decision to invest in energy efficiency and no effect on the decision to adopt renewable energy. A household living in a non-detached dwelling is less likely to invest to reduce its energy consumption. As shown in Santin et al. (2009), non-detached dwellings use less energy than detached dwellings. In this sense, households that live in non-detached dwellings and thus consume less electricity, have less incentive to reduce their energy consumption. Similarly, Sardianou (2008) find that dwelling size positively affects energy use. As suggested by our results, a household with a larger dwelling, thus consuming more electricity, has a greater incentive to reduce its electricity consumption, and is more likely to invest in energy efficiency. These results show that a household that consumes more electricity due to the characteristics of the residence, has greater incentive to invest in energy efficiency.

Environmental motivation

Our results show that environmental motivations have a mixed effect on both investment in energy efficiency and adoption of renewable energy. That is to say, people who think that environmental issues are generally more important than other issues (unemployment, economic crisis, etc.) are more likely to invest in renewable energy. This is consistent with results in Gerpott and Mahmudova (2010) and Zorić and Hrovatin (2012). In fact, renewable energy adoption is mainly guided by environmental motives. For example, the cost of electricity generated from a residential PV system after subsidies is still higher than that generated from the power grid and those who adopt residential PV consider the environmental benefits to be the most important factor in their decision-making (Zhai and Williams, 2012). People for whom environmental issues are the priority and who are likely aware that renewable energy is a clean alternative and helps protect the environment, will have more motivation to overcome barriers to adopting renewable energy.

In addition to reducing CO_2 emissions, investments in energy efficiency are also undertaken to save money. So, people who want to save money on their energy bill can be motivated to invest in energy efficiency, as can people who are pro-environmental. Therefore, environmental motivation does not have a significant effect on their decision to invest in energy efficiency. However, when it comes to comparing specific environmental issues, people who think the problem of climate change is the priority are more likely to invest in energy efficiency, while those who see the problem of resource depletion as the priority are less motivated to invest in energy efficiency. They may prefer alternative sources of energy which do not rely on depletable energy resources.

These results confirm the importance of environmental concerns in a household's decision to adopt renewable energy, while climate change concerns lead investments in energy efficiency.

Commitment and trust

As in the case of general environmental issues, we find that commitment to environmental organizations (donation or physical participation) has no significant effect on the decision of households to invest in energy efficiency, while it has a positive effect on their decision to adopt renewable energy. Additionally, commitment to local and charitable organizations positively affects the two decisions. In fact, energy issues can be related to public goods and also treated as a local problem. Mostly, people participate in environmental organizations in order to protect the environment, which itself is a public good. As renewable energy is not polluting and then not negatively affecting the environment, it may offer more incentive to consume cleaner electricity. But this is not the case for investment in energy efficiency, which is guided by both the reduction of CO_2 emissions and saving money.

Moreover, an altruist who participates in a charitable organization is more likely to be favorable to the two adoptions that could help to reduce CO_2 emissions and which is beneficial for future generations. Some environmental problems related to energy use (such as air pollution) are also local issues and so may be of great interest to local organizations. We also find that trust in researchers, scientists and experts has a positive effect on both adoptions, while trust in local or national authorities has a positive effect only on the adoption of renewable energy. As there is a large consensus among scientists regarding the negative consequences of using polluting energy sources as well as the importance of saving energy and adopting cleaner energy, people who trust scientists are more likely to invest in the two.

These results mainly suggest that when households are committed to local and charitable organizations and when they also believe researchers, scientists and experts, they are favorable to the two decisions. Whereas commitment to environmental organizations only affect the decision to adopt renewable energy.

Energy-related issues

Additionally, we focus on some specific energy-related considerations. We find that people who take into account the cost of electricity before renting or buying a house are more likely to invest in energy efficiency, while there is no significant effect on the adoption of renewable energy. The intuition is that people who do not care much the cost of electricity before renting or buying a house may be less motivated to reduce their energy bill, and are therefore less likely to invest in energy efficiency. Also, the fact that a household has access to differentiated peak and off-peak electricity rates does not significantly affect their decision to invest in energy efficiency. This can be explained by the fact that the dynamic pricing has some disadvantages, although it may help to reduce the energy bill. For example, scheduling energy use requires time and effort, and one cannot use electricity at the most convenient time. Surprisingly, paying according to the amount of electricity (for example through individual electricity metering) does not significantly affect a household's decision to invest in energy efficiency. Though investment in energy efficiency maybe more profitable if there is individual electricity metering which prevents free-riders, people may have motivations other than reducing their own energy bill.

Robustness check

In order to check whether the specifications of our model influence our main results, we perform some robustness check across sets of possible controls and variable definitions. First, we extend energy efficiency to non-monetary investments, also called curtailments in order to test whether the result of the financial capacity of the household influences its decision to invest in energy efficiency is robust. In this sense, we now focus on energy conservation actions that can be both monetary and non-monetary investments. Almost 9% of our sample adopts curtailment behaviors and do not adopt monetary investments in energy efficiency. The results are presented in Table 6 (see appendix C). We find that including non-monetary investments mostly affects results related to energy conservation. For the most part, size of residence, income, commitment to charitable and local organizations, and taking into account energy costs before buying or renting a house become non significant. In fact, most of these variables are related to the monetary capacity of the household. The energy conservation decision of a household may not be affected by those variables as curtailment behaviors are not limited by financial capacity.

Second, we test whether the impact of income on the adoption of renewable energy changes if we control for the effect of country and if renewable energy adoption does not include buying green electricity. In fact, renewable energy incentive and financial support policies are not harmonized around the world. Each country has its own policy. Also, buying green electricity does not necessitate large investments such as production of solar or wind energy. For this reason, we only focus on adoption of renewable energy as an investment decision for wind turbines and solar panels. The results (see Table 7 in Appendix C) show that after controlling for country-specific effects, the effect of income on renewable energy adoption becomes significant. Moreover, when we also consider investment decisions related to wind and solar energy, we find that income does not significantly influence a household's decision to invest in renewable energy. These results reveal that a diversity of renewable energy policies may explain why income does not significantly influence renewable energy adoption. Households are also affected differently by their financial capacity with regard to their adoption decision (including green electricity) and investment decision (only wind or solar energy).

Third, we check the robustness of our results excluding tenants and all households not living in detached or semi-detached residences. In fact, only owners can undertake investments at home due to housing regulations in most cases. Therefore, tenants have limited possibilities to invest in renewable energy and in energy efficiency. Moreover, it is technically difficult to undertake these investments when living in a flat. We find that the main results are not altered when excluding tenants and households living in a collective residence (see Table 8 in Appendix C). Fourth, in order to check the robustness of our results with respect to attitudinal characteristics such as perception, commitment and trust, we compare the results with and without attitudinal characteristics. We find that there is no change in the significance of the other variables and in the sign of the effects. Also, there is only a slight difference in the coefficients of these variables (see Table 9 in appendix C). Finally, note that the results of all the above tests confirm that there is a significant and positive interrelation between the two decisions of the household (to adopt renewable energy and to invest in energy efficiency).

Five key points emerge from the results related to households deciding to adopt renewable energy and also to invest in energy efficiency. First, the results show that there is a positive interrelation between the decision of the household to invest in energy efficiency and that of adopting renewable energy. This is due to unobserved characteristics such as environmental motivation. Second, there is evidence of energy poverty related to energy efficiency investments. Third, problems related to split incentives appear to be a barrier to the adoption of renewable energy as well as to investments in energy efficiency. Fourth, the results confirm the importance of concern for the environment in the decision of a household to adopt renewable energy, while concern over climate change leads investments in energy efficiency. Finally, the results suggest that when households are committed to local and charitable organizations and when they also believe researchers, scientists and experts, they are favorable to the two decisions. Whereas commitment to environmental organizations only affects the decision to adopt renewable energy.

4.4 Determinants of the joint adoption of renewable energy and energy efficient technologies

We now focus on factors that affect the joint probability (RE=1 and EE=1) to explain why some households decide to invest both in energy efficiency and in renewable energy. The marginal effects of the joint probability are computed from the bivariate probit model and are presented in Table 5. The results show that the significance and the sign of the effects are the same for the biprobit and the joint probability regarding living in a non-detached residence, ownership, commitment to charitable and in local organizations, trust in scientists and importance of label to reduce energy use.

Energy poverty, split incentives and environmental motivation

There is no significant effect of the household income on its decision to jointly adopt renewable energy and energy efficient technologies. In this sense, the influence of income becomes less important in the decision of the household to go further when it has undertaken any of these investments. In fact, by undertaking one of the investments, the household reduces its total energy expenses which contributes to relax the “energy budget” constraint of the household. Consequently, the household can then take on the additional investment. Unsurprisingly, we also find that tenants are less likely to combine the two investments due to split incentives. However, this limitation can be overcome by environmental motivations. In this sense, people who have already undertaken one of the investments and for whom environmental issues are generally more important than non-environmental issues are more likely to have the additional motivation to overcome barriers that could prevent them from fully contributing to the energy transition.

Dwelling characteristics, attitudinal and energy-related effects

A household that has already undertaken one of the investments and who is living in a detached dwelling is more likely to make additional efforts to invest in the second, while residence size has no significant effect. We also find that participation in charitable, environmental and local organizations, and trust in scientists and local authorities have a positive effect. People who are involved in such organizations and have already undertaken one of the investments are more likely to understand the importance of the energy transition, which itself is related to environmental and local problems and intergenerational equity. Moreover, scientists or national or local authorities are the most suited to communicating about the energy transition. Therefore, people who trust them are more likely to invest in both energy efficiency and renewable energy. The results also show that taking into account energy cost before renting or buying a house has no significant effect on the decision of the household to combine investments in energy efficiency and renewable energy. However, this has a positive effect on the decision to invest in energy efficiency, and no effect on the decision to adopt renewable energy (biprobit). Like in the biprobit model, having individual

Table 5: Bivariate probit Model and joint probability of RE=1 and EE=1

	Biprobit		Joint probability
Variables	EE	RE	RE=1 and EE=1
Residential and economic variables			
Living in a non-detached residence	–0.0736**	–0.0550*	–0.0219**
	(0.0364)	(0.0310)	(0.0107)
Size of the residence	0.0650***	–0.00447	0.0015
	(0.0233)	(0.0202)	(0.0070)
Household income	0.0271***	0.00289	0.0022
	(0.00630)	(0.00529)	(0.0018)
Owner	0.151***	0.100***	0.0406***
	(0.0383)	(0.0335)	(0.0113)
Perception, commitment and trust			
Environmental concerns (general issues)	–0.00746	–0.0235***	–0.0083***
	(0.0105)	(0.00896)	(0.0031)
Climate change	–0.0652**	0.0709***	0.0209**
	(0.0267)	(0.0247)	(0.0085)
Resource depletion	0.0753***	–0.0339	–0.0079
	(0.0292)	(0.0277)	(0.0095)
Voting in local elections	0.0789**	0.0264	0.0126
	(0.0369)	(0.0328)	(0.0112)
Commitment to charitable organizations	0.147***	0.133***	0.0523***
	(0.0412)	(0.0322)	(0.0115)
Commitment to environmental organizations	0.0584	0.168***	0.0608***
	(0.0486)	(0.0394)	(0.0142)
Commitment to local organizations	0.116**	0.0996***	0.0395***
	(0.0475)	(0.0373)	(0.0133)
Trust in scientists	0.0541***	0.0696***	0.0260***
	(0.0147)	(0.0148)	(0.0051)
Trust in local authorities	0.00167	0.0316**	0.0108**
	(0.0136)	(0.0126)	(0.0044)
Energy use			
Energy costs before buying or renting a house	0.104***	0.0348	0.0165
	(0.0367)	(0.0311)	(0.0109)
Individual metering	0.0771	0.0994	0.0363
	(0.0862)	(0.0787)	(0.0261)
Peak Tariff	0.0202	–0.375***	–0.1239***
	(0.0330)	(0.0286)	(0.0095)
Label to reduce energy use	0.184***	0.183***	0.0680***
	(0.0561)	(0.0582)	(0.0183)
rho	0.1660***		
	(0.0236)		
Log pseudolikelihood	–9077.8972		
Observations	11198		

***1%, **5%, *10% and ()= robust std errors. The joint probability column provides marginal effects.

metering does not affect the joint adoption of the household while having access to dynamic pricing has a negative effect.

The results regarding the joint adoption of renewable energy and energy efficient technologies suggest two main findings. First, the influence of income becomes less important in the decision of the household to go further when it has undertaken any of these investments. Second, barriers to the full contribution to the energy transition can be overcome by environmental motivations.

5. CONCLUSION

Investigating the relationships between household decisions related to investing in energy efficiency and adopting renewable energy is of great interest from policy perspective. This paper fills this gap in the literature and first uses a simple theoretical model to show that there are relationships of substitution or complementarity between the two decisions depending on a cross effect which relies on environment-related satisfaction. Second, using a bivariate probit model the paper empirically shows that there is a positive interrelation between the decisions of the household to invest in energy efficiency and to adopt renewable energy, due to unobserved characteristics such as environmental motivations. Third, the paper provides evidence about factors that affect the probability of adopting renewable energy and that of investing in energy efficiency. Notably, people living in poorer households are less likely to invest in energy efficiency and may end up using a large share of their income to pay for electricity, and be in a situation of energy poverty. There is evidence of split incentives: ownership positively affects both the probability to invest in renewable and in energy efficiency.

The results also confirm the importance of environmental concerns in a household's decision to adopt renewable energy, while climate change concerns lead investments in energy efficiency. Finally, the results suggest that when households are committed to local and charitable organizations and when they believe researchers, scientists and experts as well, they are favorable to the two decisions. However, commitment to environmental organizations only affects their decision to adopt renewable energy. Fourth, we focus on the motivations of the household to jointly adopt renewable energy and energy efficient technologies. The results mainly suggest that (i) the influence of income becomes less important in the decision of the household to go further when it has undertaken any of these investments and (ii) barriers to full contribution to the energy transition can be overcome by environmental motivations.

With respect to policy, one should first consider the two decisions when designing incentive instruments for renewable energy adoption and for energy efficiency investment. Policies that rely on factors that jointly affect the two decisions would benefit from the synergies that may exist between them. For example, promoting a net zero-energy building by investing in both energy efficiency measures and renewable energy would facilitate reliance solely on renewable energy sources. Energy demand would therefore be markedly reduced due to efficiency gains, so that the remaining energy needs would be satisfied by means of renewable energy. Second, regulation of housing markets could help address split incentives by offering incentives to tenants to undertake investments in energy efficiency and in renewable energy as well. Financial support to reduce the costs of dismantling and re-installation of renewable energy equipment could provide incentives to tenants to undertake such investments as well. Third, policies targeting investment in energy efficiency need to be improved. In many countries, financial support for energy conservation systems are mainly profitable for wealthier households. Poorer households are financially limited, the requirement to invest before applying for reimbursement renders participation in financial support schemes unaffordable. Therefore, it is necessary to set green grants which should be interest-free eco-loans targeting only energy-poor households. Fourth, it may be of great interest to work with existing charitable, environmental and local organizations to communicate with their members on the importance of energy transition. They are predisposed to better understanding the crucial contribution of the energy transition in protecting the environment. Moreover, scientists or national or local authorities are the most suited to communicating about the energy transition. Therefore, they should be more involved in raising awareness and in publicizing academic findings to a mainstream audience.

However, there are many others factors which we could not consider in this paper and that may limit tenants ability to install renewable energy equipment. For example, living in an apartment without a balcony, having limited space on the rooftop, etc. may limit the possibility of installing renewable energy equipment. Variables related to characteristics of the residence such as the age of the dwelling and the type of insulation could influence a household's decision of the to invest in energy efficiency. These variables are not provided in the EPIC survey and deserve further research. This paper can be extended to empirically identify the cross effect by comparing the rates of adoption of renewable energy (energy efficient technologies respectively) across households with and without pre-existing energy efficient technologies (renewable energy respectively). Another possible extension would be to analyze the differential of economic incentives across the two decisions and its effect on the decisions of the household.

6. APPENDIX

6.1 Appendix A

Proof of Proposition 1

The household solves the following program.

$$\begin{aligned}&\max_{d,ee,re} \sum_{t=0}^{p} \beta^t U\left(ee, re, d\right)\\ &\quad st \qquad R = d_t + d_{-t} + k_1 ee + k_2 re\end{aligned}, \tag{9}$$

and the optimal allocation is given by

$$\alpha'(ee)u'(re+d) + \frac{\partial v}{\partial ee} = \frac{k_1}{k_2 - 1}\frac{\partial v}{\partial re}. \tag{10}$$

We can derive an implicit function Q from Eq. (10) by replacing d from (1).

$$Q \equiv -ee + \frac{1-k_2}{k_1}re + \frac{R-d_{-t}}{k_1} + \frac{1}{k_1\alpha'(ee)u'}\left(\frac{k_1}{1-k_2}\frac{\partial v}{\partial re} + \frac{\partial v}{\partial ee}\right).$$

We use this implicit function Q to derive the derivative of the optimal level of investment in energy efficiency with respect to the optimal level of investment in renewable energy. Taking total derivative of Q, we get:

$$\frac{\partial Q}{\partial re}dre + \frac{\partial Q}{\partial ee}dee = 0.$$

We can then deduce that:

$$\frac{dee}{dre} = -\frac{\frac{\partial Q}{\partial re}}{\frac{\partial Q}{\partial ee}},$$

where

$$\frac{\partial Q}{\partial re} = \frac{1-k_2}{k_1} + \frac{1}{k_1\alpha'(ee)u'}\left[-\frac{(1-k_2)\alpha(ee)u''}{u'}\left(\frac{k_1}{1-k_2}\frac{\partial v}{\partial re} + \frac{\partial v}{\partial ee}\right) + \frac{\partial^2 v}{\partial ee \partial re}\right] \tag{11}$$

and

$$\frac{\partial Q}{\partial ee} = -1 + \frac{1}{k_1 \alpha' u'}\left[-\left[\frac{\alpha''}{\alpha'} + (re + d - k_1 \frac{\alpha}{\alpha'}) \frac{u''\alpha'}{u'} \right] \left(\frac{k_1}{1-k_2} \frac{\partial v}{\partial re} + \frac{\partial v}{\partial ee} \right) + \frac{k_1}{1-k_2} \frac{\partial^2 v}{\partial ee \partial re} \right] \qquad (12)$$

Equation (10) gives:

$$\frac{\partial v}{\partial ee} + \frac{k_1}{1-k_2} \frac{\partial v}{\partial re} = -\alpha' u'(re + d). \qquad (13)$$

Replacing equation (13) into equation (11), gives:

$$\frac{\partial Q}{\partial re} = \left(1 - \frac{1}{\varepsilon} \right) \frac{1-k_2}{k_1} + \frac{1}{k_1 \alpha' u'} \frac{\partial v}{\partial ee},$$

where $\varepsilon = -\frac{u'}{\alpha(re+d)u''}$ is the elasticity of intertemporal substitution.

As $k_2 > 1$ and $\varepsilon \le 1$ by assumptions, $\frac{\partial Q}{\partial re} > 0$. Therefore, the sign of $\frac{dee}{dre}$ depends on the sign of $-\frac{\partial Q}{\partial ee}$.

Furthermore, equation (4) gives:

$$\alpha'(re + d - \frac{\alpha}{\alpha'} k_1) = -\frac{\partial v}{\partial ee} \frac{1}{u'} \qquad (14)$$

Replacing equations (13) and (14) into equation 12, gives:

$$\frac{\partial Q}{\partial ee} = -1 + \frac{1}{k_1 \alpha' u'} \left[\alpha'' u'(re + d) + \frac{\alpha'^2}{\varepsilon\alpha} \frac{\partial v}{\partial ee} + \frac{k_1}{1-k_2} \frac{\partial^2 v}{\partial ee \partial re} \right]$$

Thus,

$$\frac{\partial Q}{\partial ee} > 0 \Leftrightarrow \frac{\partial^2 v}{\partial ee \partial re} < \overline{v_{eere}} = \frac{1-k_2}{k_1} \left[k_1 \alpha' u' - \alpha'' u'(re + d) - \frac{\alpha'^2}{\varepsilon\alpha} \frac{\partial v}{\partial ee} \right]$$

We can then deduce the following condition:

$$\frac{dee}{dre} > 0 \Leftrightarrow \frac{\partial^2 v}{\partial ee \partial re} > \overline{v_{eere.}}$$

6.2 Appendix C

Table14: Description and summary of independent variables.

Variables	Description	Mean
Residential and Socio-demographic variables		
Living in a non-detached residence (collective)	1 for non-detached and 0 for detached	.43
Size of the residence (size_residence)	1-<50m^2; 2-50-100; 3-100-200 ; 4->200	2.41
Age of the respondent (age)	Continuous variable	42.53
Gender of the respondent (sex)	0 for Female and 1 for Male	.49
Employment status (employme)	0 for not working and 1 for working	.63
Household income (income)	1 for usd 1- usd 24200….up to 10 for more than usd 127000	5.0
Size of household (size_hh)	1 for 1… up to 5 for 5+	2.86
Ownership (owner)	0 for no owner and 1 for owner	.64
Urban or non-urban residence (urban)	0 for not living in urban area and 1 for living in urban area	.70
Duration of residence (duration)	1 for less than 2 years… up to 4 for more than 15 years	2.62
Attitudinal variables		
Perception		
Environmental concerns (general issues) (env_conc)	1 for most important... up to 6 for least	3.52
Air pollution (air_poll)	1 for most important... up to 4 for least	3.44
Climate change (climate_)	1 for most important... up to 4 for least	3.35
Resource depletion (resource)	1 for most important... up to 4 for least	3.46
Waste generation (waste_ge)	1 for most important... up to 4 for least	3.33
Commitment and trust		
Voting in local elections (vote_loc)	0 for no and 1 for yes	.70
Commitment to charitable organisations (com_char)	0 for no and 1 for yes	.24
Commitment to environmental organisations (com_env)	0 for no and 1 for yes	.14
Commitment to local organisations (com_loca)	0 for no and 1 for yes	.15
Trust in scientists (trust_sc)	1 for least truthworthy... up to 5 for most	3.80
Trust in local authorities (trust_lo)	1 for least truthworthy... up to 5 for most	2.68
Trust in manufacturers (trust_ma)	1 for least truthworthy... up to 5 for most	2.34
Trust in NGOs (trust_NG)	1 for least truthworthy... up to 5 for most	3.51
Energy use and other variables		
Individual metering (ind_mete)	0 for no and 1 for yes	.95
Peak Tariff (peak)	0 for no and 1 for yes	.45
Energy costs before buying or renting a house (exante)	0 for no and 1 for yes	. 29
Importance of information to reduce energy use (est_info)	0 for no and 1 for yes	.88
Importance of environmental benefits to reduce energy (est_env)	0 for no and 1 for yes	.88
Importance of label to reduce energy use (est_labe)	0 for no and 1 for yes	.88
Importance of less expensive EE to reduce energy use (est_lexp)	0 for no and 1 for yes	.89
Year of the survey (year)	0 for 2008 and 1 for 2011	.54

Table 6: Robustness check: Estimation of Bivariate probit with both monetary and non-monetary investments in energy efficiency

	Biprobit	
Variables	EE2	RE
Residential and economic variables		
Living in a non-detached residence	–0.325***	–0.0468*
	(0.0501)	(0.0284)
Size of the residence	–0.00116	–0.0159
	(0.0318)	(0.0187)
Household income	–0.00223	0.00429
	(0.00855)	(0.00488)
Ownership	0.110**	0.0809***
	(0.0501)	(0.0300)
Perception, commitment and trust		
Environmental concerns (general issues)	–0.0151	–0.0264***
	(0.0141)	(0.00815)
Climate change issues	–0.0919***	0.0823***
	(0.0351)	(0.0232)
Resource depletion issues	0.159***	–0.0369
	(0.0382)	(0.0259)
Voting in local elections	0.118**	0.0379
	(0.0491)	(0.0298)
Commitment to charitable organisation	–0.00537	0.133***
	(0.0538)	(0.0294)
Commitment to environmental organisation	–0.0826	0.150***
	(0.0629)	(0.0364)
Commitment to local organisation	0.0973	0.0864**
	(0.0639)	(0.0347)
Trust in scientists	0.0787***	0.0724***
	(0.0183)	(0.0138)
Trust in local authorities	–0.0159	0.0208*
	(0.0177)	(0.0119)
Energy use		
Energy costs before buying or renting a house	0.0272	0.0213
	(0.0490)	(0.0283)
Individual metering	0.0748	0.0730
	(0.110)	(0.0712)
Peak Tariff	–0.00400	–0.404***
	(0.0437)	(0.0262)
Label to reduce energy use	0.276***	0.168***
	(0.0708)	(0.0539)
rho	0.1876459 1***	
	(0.0312183)	
Log pseudolikelihood	–8321.7626	
Observations	13133	13133

***1%, **5%, *10% and ()= robust std errors.

Table 7: Robustness check: Estimation of Bivariate model with solar/wind energy and country effects

	With country effects		Country effects+ solar/wind energy	
Variables	EE	RE	EE	RE
Residential and economic variables				
Living in a non-detached residence	–0.0774*	–0.0793**	–0.175***	–0.172***
	(0.0422)	(0.0375)	(0.0468)	(0.0537)
Size of the residence	0.0405	–0.0236	0.0316	0.0889***
	(0.0251)	(0.0217)	(0.0274)	(0.0301)
Household income	0.0263***	0.0157***	0.0266***	–0.00109
	(0.00661)	(0.00572)	(0.00712)	(0.00782)
Owner	0.138***	0.0410	0.185***	0.257***
	(0.0406)	(0.0364)	(0.0449)	(0.0573)
Perception, commitment and trust				
Environmental concerns (general issues)	–0.0278**	–0.0466***	–0.0184	–0.0201
	(0.0114)	(0.00964)	(0.0124)	(0.0132)
Climate change issues	–0.00584	0.0542**	0.00281	0.0348
	(0.0278)	(0.0255)	(0.0310)	(0.0349)
Resource depletion issues	0.0463	–0.00680	0.0434	–0.0521
	(0.0306)	(0.0284)	(0.0337)	(0.0373)
Voting in local elections	0.0443	0.0353	0.0335	–0.0309
	(0.0395)	(0.0359)	(0.0431)	(0.0494)
Commitment to charitable organisations	0.0788*	0.0996***	0.0898*	0.00181
	(0.0436)	(0.0342)	(0.0472)	(0.0475)
Commitment to environmental organisations	0.0773	0.207***	0.0713	0.275***
	(0.0513)	(0.0426)	(0.0570)	(0.0561)
Commitment to local organisations	0.113**	0.0934**	0.0726	0.153***
	(0.0502)	(0.0386)	(0.0537)	(0.0511)
Trust in scientists	0.0224	0.0266*	0.0284*	–0.0174
	(0.0157)	(0.0150)	(0.0172)	(0.0193)
Trust in local authorities	0.00296	0.0154	–0.00112	0.0557***
	(0.0144)	(0.0133)	(0.0157)	(0.0176)
Energy use				
Energy costs before buying or renting a house	0.118***	0.120***	0.142***	0.248***
	(0.0387)	(0.0331)	(0.0424)	(0.0439)
Individual metering	0.170*	0.0653	0.188*	–0.0452
	(0.0903)	(0.0856)	(0.0993)	(0.125)
Peak Tariff	0.0256	–0.237***	0.0263	0.183***
	(0.0364)	(0.0317)	(0.0397)	(0.0447)
Label to reduce energy use	0.203***	0.258***	0.218***	0.0814
	(0.0590)	(0.0580)	(0.0652)	(0.0794)
rho	0.1604704***		0.4134992***	
	(0.025715)		(0.0471648)	
Log pseudolikelihood	–8396.4141		–5207.4594	
Observations	11198		9410	

***1%, **5%, *10% and ()= robust std errors.

Table 8: Robustness check: Estimation of Bivariate model excluding tenants and households living in a collective residence

	Excluding tenants		Excluding collective house	
Variables	EE	RE	EE	RE
Residential and economic variables				
Living in a non-detached residence	–0.0743	–0.0007		
	(0.0456)	(0.0364)		
Size of the residence	0 .0585**	0 .0259	0.0968***	0.00405
	(0.0286)	(0.0230)	(0.0286)	(0.0227)
Household income	0 .0341***	0.0061	0.0308***	0.00774
	(0.0074)	(0.0059)	(0.00817)	(0.00647)
Owner			0.166***	0.0291
			(0.0561)	(0.0460)
Perception, commitment and trust				
Environmental concerns (general issues)	–0.0146	–0.0213**	–0.00309	–0.0289**
	(0.0130)	(0.0104)	(0.0144)	(0.0114)
Climate change issues	–0.0745**	0.0778***	–0.0922**	0.0707**
	(0.0331)	(0.0287)	(0.0366)	(0.0306)
Resource depletion issues	0.106***	–0.0313	0.119***	–0.00876
	(0.0370)	(0.0321)	(0.0399)	(0.0344)
Voting in local elections	0.0965**	0.0733*	0.0583	0.0555
	(0.0482)	(0.0401)	(0.0521)	(0.0426)
Commitment to charitable organisations	0.156***	0.118***	0.159***	0.101**
	(0.0507)	(0.0370)	(0.0567)	(0.0400)
Commitment to environmental organisations	0.0429	0.175***	0.116*	0.169***
	(0.0587)	(0.0452)	(0.0683)	(0.0486)
Commitment to local organisations	0.114**	0.0939**	0.105*	0.0914**
	(0.0560)	(0.0416)	(0.0604)	(0.0437)
Trust in scientists	0.0712***	0.0710***	0.0668***	0.0795***
	(0.0184)	(0.0172)	(0.0199)	(0.0184)
Trust in local authorities	0.0152	0.0240	–0.00379	0.0406**
	(0.0170)	(0.0146)	(0.0186)	(0.0158)
Energy use				
Energy costs before buying or renting a house	0.108**	–0.00404	0.0963*	0.0237
	(0.0452)	(0.0358)	(0.0493)	(0.0384)
Individual metering	0.0416	0.00299	0.136	–0.0703
	(0.126)	(0.108)	(0.130)	(0.113)
Peak Tariff	–0.0190	–0.374***	0.0218	–0.394***
	(0.0409)	(0.0329)	(0.0442)	(0.0349)
Label to reduce energy use	0.132*	0.171***	0.154**	0.148**
	(0.0705)	(0.0663)	(0.0754)	(0.0715)
rho	0.1543***		0.1872***	
	(0.0285)		(0.0311)	
Log pseudolikelihood	–6401.8768		–5424.1275	
Observations	8036		6721	

***1%, **5%, *10% and ()= robust std errors.

Table 9: Robustness check: estimation with and without attitudinal variables

	(With) EE	(Without) EE	(With) RE	(Without) RE
collective	–0.0736**	–0.0869*	–0.0550*	–0.0477
	(0.0364)	(0.0356)	(0.0310)	(0.0304)
size_residence	0.0650***	0.0801***	–0.00447	0.0117
	(0.0233)	(0.0228)	(0.0202)	(0.0199)
income	0.0271***	0.0287***	0.00289	0.00579
	(0.00630)	(0.00609)	(0.00529)	(0.00519)
owner	0.151***	0.164***	0.100***	0.0995**
	(0.0383)	(0.0374)	(0.0335)	(0.0329)
exante	0.104***	0.123***	0.0348	0.0519
	(0.0367)	(0.0359)	(0.0311)	(0.0303)
ind_metering	0.0771	0.0838	0.0994	0.0832
	(0.0862)	(0.0844)	(0.0787)	(0.0776)
peak	0.0202	0.0281	–0.375***	–0.370***
	(0.0330)	(0.0324)	(0.0286)	(0.0281)
est_label	0.184***	0.207***	0.183***	0.216***
	(0.0561)	(0.0542)	(0.0582)	(0.0575)
N	11198	11444		

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

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