International Scholars Journals

African Journal of Environmental Economics and Management ISSN 2375-0707 Vol. 5 (3), pp. 302-315, March, 2017. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Are investments in energy efficiency and renewable energy technologies complementary? An econometric analysis of households' environmental investments

George Abuchi Agwu

Federal University, Ndufu-Alike Ikwo, Nigeria.
E-mail: george78ng@yahoo.com.

Accepted 14 November, 2016

Economic incentives have received much attention in the literature of the two dimensions of environmental friendly energy consumption: energy efficiency and renewable energy investments. This study shows that the incentives, if not well targeted may be irrelevant because household investors in the different dimensions possess different characteristics that policies could target. The findings indicate that investments in renewable energy technologies decrease with age of household investors and not affected by household income constraint while investments in energy efficiency are not affected by age of household investors but by income constraint. Correlation coefficients among all the investment equations in the multivariate model are strongly positive suggesting complementary investment choices across dimensions.

Keywords: Energy efficiency, renewable energy, multivariate probit, ordered probit.

INTRODUCTION

As scarcity of natural resources and environmental degradation get more national and international attention, calls for sustainable energy consumption get intensified. Most governments in the developed world employ incentives or information campaigns to promote energy savings and other eco-friendly behaviours. With respect to purchase of eco-friendly appliances, many empirical studies have assessed how measures such as eco-labelling, tax incentives, and subsidization policies impact on the governments objectives. However, most of these studies employ univariate methodologies that assume independent decisions with respect to the various dimensions of pro-environmental behaviours.

Although industry and agriculture represent the bulk of energy demand, there exists substantial potential to reduce total energy demand in the residential sector. As mentioned above, a lot of policy efforts are presently concentrated at demand side management (DSM) policies, i.e., price and non-price policies designed to promote energy conservation in the residential sector. This opens up a number of choice for household energy consumption: In order to reduce the quantity of energy for a given energy service, a household can decide to invest in energy efficient technology that induces energy saving or decide to reduce energy waste by engaging in prudential energy use such as switching off standby model of appliances when not in use (Jansson et al., 2009). By reducing its consumption of energy, the household contributes to reducing future greenhouse gas (GHG) emissions. Reducing greenhouse gas emission can also be achieved by investing in renewable energy technologies such as wind turbine, ground source heat pump or solar panel. The use of renewable energy technologies differs from the other forms of sustainable energy consumption because for a given level of renewable energy consumption, less greenhouse gases are emitted.

The relationship among these choices of responsible energy use is an important policy consideration. For instance, energy efficiency technology investments and prudential energy use maybe driven by money savings, environmental consciousness or both. On the other hand, investment in renewable energy technology are most likely driven by environmental consciousness and other non-monetary concerns. If households are simultaneously environmentally conscious and income constrained, they could leverage on the synergy between these dimensions of pro-environmental choices as identified by Dato (2015) to satisfy their objectives. However, certain combinations of energy efficiency and renewable energy technologies may be more appealing to the households than others. For instance, households may favour energy efficiency-wind turbine combination or energy efficiency- solar panel combination due to for example existing policies or space requirement. Thus, the lumping together in two groups of all energy efficiency and renewable energy investments do not provide a clear path for policy mediation. Furthermore, prudential energy use is more of an attitude than a decision: such that its role is to predict energy efficiency, renewable energy investments or both rather than being an alternative choice as Dato (2015) suggests.

LITERATURE REVIEW

Empirical determinants of Pro-Environmental Decisions

The traditional economic theory examines household's behaviour on the basis of consumption as broadly defined in terms of households 'purchases and other decisions such as labour supply. The idea is that households' decisions are described by utility function subject to budget constraint and other household's characteristics which generates testable restrictions on household's behaviour. The Household characteristics include disposable household income, age, gender, education, occupation, marital status, family size and number of children. Empirical studies of energy efficiency and renewable energy technologies adoption suggest that these characteristics are important decision variables: household size is hypothesized to predict adoption because budget constraints increase in household size given limited number of income earners within the household. On the other hand, large household increases the incidence and size of economics of scale of energy savings incident upon adoption of the appliance. So on the one hand, households size may tighten the constraint faced by households with respect to clean energy adoption. On the other hand, household's size increases, the private benefits derivable through clean energy adoption. This is thus one critical testable hypothesis. Millock and Nauges (2010) found a positive and significant relationship between the household size and the adoption of water saving technologies.

Socio-Economic Characteristics

Household's income represents largely the budget to be maximized and thus all things being equal, adoption of clean energy is expected to rise with income. However, on the basis of economic theory, the role played by income in driving households' decisions is difficult to assess. On the one hand wealthier households should have greater financial ability to invest in energy-saving appliances. On the other hand, wealthier households could have less elastic demand for consumption in general compared to poorer households. Not surprising therefore, empirical studies have found varied results regarding household income. Whereas, Berk et al. (1993) shows that income has positive effect on water conservation, De Oliver (1999) shows that lower income households are more conservative of water than higher income households. Sütterlin et al. (2011) found that lower-income households were more likely to adopt energy saving habits. Martínez-Espiñeira and García-Valiñas (2013) also found negative relationship between income levels and the adoption of water conservation behaviour.

A higher education level is expected to be positively correlated with knowledge and awareness about issues relating to the environment. Thus, it is expected apriori that more educated households/respondents are more likely to undertake pro-environmental actions given their knowledge. The analysis of the OECD survey undertaken in eleven countries showed that the level of educational attainment increased pro environmental behaviours in all the five areas (transportation, water, energy, waste, and food) covered (OECD, 2011). This was confirmed empirically by Martínez-Espiñeira and García-Valiñas (2013). The roles played by marital status, age and occupation varies substantially depending on the dataset and technologies being studied (see Ameli and Brandt, 2015)

Social and Relational Factors

The social system or norms just like the cost benefit analyses in the case of energy efficiency investment may affect the adoption of environmentally friendly behaviours. In addition to environmental concern, Zhai and Williams (2012) investigates the influence of social acceptance and shows in a specific case of photovoltaic (PV) adoption that social acceptance also affects the adoption of renewable energy. In a model grounded in diffusion of innovation and social capital theories, McMichael and Ship worth (2013) underscore social system as important factor in the diffusion of environmentally friendly energy technologies. In particular, McMichael and Shipworth (2013) emphasized that word-of-mouth and experience of innovators is far more potent than standard campaigns and advocacy in the diffusion of clean energy innovations among British communities.

Those community members who are seen as opinion leaders might influence other members of the community towards a particular orientation with respect to the desirability of environmentally friendly energy technologies. Mills and schleich (2012) explored how opinion leadership contributes to the innovativeness of adopters and found that those classified as opinion leaders are more likely to be among the first 5% of adopters of given innovation. Nair et al. (2010) show that adoption is associated with income, education and age but suggest that opinion leaders influence non-adopters through personal communication channels that maybe fostered by policy.

Moral Hazard and Spillovers

Many other factors not classified above have been shown to matter for household's consideration of adopting environmentally friendly energy technology. These factors may be related to tenure in primary accommodation, incentives structure and spillover effects. For instance, at what point during the households' residency in the primary accommodation is it optimal to install energy efficiency or environmentally friendly energy technology? Most empirical studies find evidence of positive tenure effect (Davis, 2010;Murray and Mills, 2011; Martínez-Espiñeira and García-Valiñas 2013). However, Tovar (2012) found negative effect of tenure on household's adoption of energy efficiency eco-innovation in the UK. The most common justification for positive tenure effect is that as households develop attachment to their current residence, they become more likely to install measures to make it compliant to sustainable consumption of energy. However, the question of when to install these measures depends also on the particular type of measure under consideration. While it might be optimal to install measures that have to do with the built environment such as cavity walls insulation at the beginning of residency when other renovations or constructions are going on, for others such as light bulbs anytime may be just fine for adoption. Given that Tovar, (2012) model was based on cavity walls insulation, loft insulation and boiler upgrade, this result is not at all surprising.

Split incentives between landlords who install energy using equipment in rental accommodations and renters who pay the energy bills has been extensively studied as factors that may get in the way of households' energy efficiency behaviour. Landlords may buy cheap inefficient appliances when it is the responsibility of the tenants to pay the energy bills. Davis (2010) empirically compared appliances ownership patterns between homeowners and renters and found that renters are less likely to have efficient appliances compared to homeowners. This is because of the lemon problem which arises from the fact that potential tenants cannot observe appropriately the quality of energy using equipment installed by the landlords (Akerlof, 1970). As a result of this, the landlords cannot possibly signal the quality of the equipment in their homes through higher rental fees (Gilligham et al., 2012)

On spillover effects, Nair et al. (2010) show that as households become aware of the benefits of adopting energy efficiency technologies through past investments, they become more likely to devote further outlay to energy efficiency. This thus implies that information acquisition, education or learning by doing is related to the unobservable driving the probability of households investing in more than one of the energy efficiency measures. Similarly, Brown (2014) show that adoption of energy conservation habits has positive spillover effects on related habits such as recycling and water conservation and is mediated by positive attitudes to the environment. A model of clean energy adoption should therefore be multi-disciplinary in nature including economic as well as other considerations that are not purely economic and consider possible relatedness among the different dimensions of environmental behaviour. Such models would estimate environmental behaviour more efficiently and identify policy relevant covariates.

The Interaction between Energy Efficiency and Renewable Energy Investments

A number of empirical studies has been conducted on how households' behaviours affect adoption and investment in energy efficiency. This is because substantial opportunities exist within the residential sector to reduce energy consumption and mitigate climate change (Fouquet, 2010; Dietz et al., 2009; and Vandenbergh et al., 2008). There is a large evidence that economic factors are motivations for energy efficiency (Kempton and Neiman, 1986; and Steg, 2008) and can be helpful in designing appropriate taxes or subsidies mechanism to promote energy saving actions. For instance, energy efficient behaviour maybe brought about by the need to save household expenses or to reduce energy bills. Achieving this objective however is not so simple; the potential gain from reducing energy use can be hindered by some problems such as split incentives, uncertainty about the gain of energy efficiency, moral hazard problem that may prevent households from adopting or investing in an energy conservation system. Reducing energy use can also lead to reverse effects such as rebound effect or take-back effect (Chitnis et al., 2014; Urban and Scasny, 2012). Problems such as rebound effects operate through household's motivations. If households are motivated by economic concerns such as savings in energy expenditure, they are more likely to be subject to rebound effects than those motivated by environmental concerns. Studies such as Urban and Scasny (2012) suggest that the rebound effect can be solved by environmental campaigns geared at cultivating pro-environmental motivation. There is however, no empirical consensus on the impact of environmental concern on energy-saving behaviour. Earlier literature found that environmental concern does not have any effect on both energy consumption and energy- saving actions (Gilligham et al.,2012). Others, mostly recent studies tend to find significant effects of environmental concerns on energy-saving actions (Capstick et al., 2015; Barr et al., 2005; and Whitmarsh and O'Neill,2010).

While energy efficiency investments correlates with the desire for money savings, empirical studies show that investment in renewable energy is driven by environmental attitudes. This follows from the theory of reasoned action which characterizes peoples' actions as arising from their cognitive assessment of possible outcomes based on held attitudes. Most empirical studies relying on consumers' stated preference tend to find strong roles for environmental attitudes in consumers' willingness to adopt clean energy technologies (Ek and Söderholm, 2008; Zoric and Hrovatin, 2012; Liu et al., 2013.). Although such hypothetical studies may deviate from observed behaviour, it clearly distinguishes renewable energy investment choice from energy efficiency investment (Cameron et el, 2002; Kotchen and Moore, 2007). Thus on apriori, those households with greater environmental consciousness are expected to engage more with renewable energy technologies than others. If they are equally conscious of money savings, then they are more likely to invest jointly in renewable and energy efficiency technologies.

Different dimensions of pro-environmental behavior may be distinguished (Lynn,2014). Both economic and environmental motivations have different effects when dimensions of environmental friendliness are distinguished. As far as energy consumption is concerned, energy efficiency can be distinguished from the use of renewable energy. The use of renewable energy has been compared to private provision of public goods and driven by altruistic motivation (Welsch and Kuhling, 2010). Energy efficiency on the other hand mainly derives from economic motivation in form of reducing expenditure (Diaz-Rainy and Ashton, 2015). Energy efficiency behaviour can be further sub-divided into energy 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 lightbulbs, energy-efficient windows, etc.) that needs monetary investment. The latter refers to non-monetary investments that are behaviour changes such as turning off lights, cutting down on heating or on airconditioning and switching off standby mode of appliances. Monetary energy efficiency investments are less affected by pro-environmental motivations than non-monetary behaviour changes (Guagnano et al., 1995). Both economic and environmental concerns may have significant effects on energy-saving actions which are the outcome of both monetary and non- monetary investments. Urban and Scasny (2012) investigates in a multi-country setting how environmental concern affects the adoption of monetary versus non-monetary investments in energy efficiency. They find a positive and significant effect of pro-environmental motivation in both cases.

Notwithstanding the distinguishing features of energy efficiency behaviour and the use of renewable energy, relevant synergies may exist between them. The different variables that affect the renewable energy adoption decision of household 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. If the two decisions are interrelated, it cannot be estimated independently. In this case, univariate models that estimate separately the two decisions of renewable adoption and energy efficiency are potentially inefficient because there may exist unobserved characteristics that motivate joint occurrence of the two decisions. For instance, household that is pro-environmental in their held attitude can find it necessary to additionally invest in renewable energy having already invested in energy efficiency. In this case, the household may rely on its environmental conscientiousness to combine the two investments. Similarly, households having invested in energy efficiency may have limited financial capacity to additionally invest in renewable energy. Therefore, by jointly analyzing the two possible decisions of the adoption of renewable energy and investment in energy efficiency that are taken by the household, one can capture the interrelation and the interaction between them. Such investigation has potential gain for policy designs as adoption of renewable energy and investments in energy efficiency are both important in the transition to green economy.

Data and variables description

The data for this study comes from 2011 OECD cross-sectional survey which collects data from a sample of more than 12 000 respondents, approximately 1000 households for each country: Australia (shorthand: AUS), Canada (shorthand: CAN), Chile (shorthand: CHL), France (shorthand: FRA), Israel (shorthand: ISR), Japan (shorthand: JPN), Korea (shorthand: KOR), the Netherlands (shorthand:NLD), Spain (shorthand:ESP), Sweden (shorthand:SWE) and Switzerland (shorthand:CHE). The sample was stratified to achieve representativeness. In each country stratification was done according to different parameters: age, gender, region and socio-economic groups.

The target respondents were between 18 and 70 years of age and those who had influence on household purchasing decision and expenditures. Gender was approximately half male and female for all countries. Region was stratified and quotas created using three to five regions. For income stratification, households' after

Table 1. Summary statistics for the dependent variables.

Country	Appl	Bulb	Windows	Thrm	Heat	Solar	Pump	Wind
			Mean					
AUSTRALIA	0.690	0.910	0.130	0.580	0.150	0.200	0.030	0.034
CANADA	0.670	0.870	0.510	0.380	0.650	0.040	0.040	0.029
CHILE	0.410	0.950	0.140	0.310	0.060	0.020	0.010	0.013
FRANCE	0.740	0.860	0.590	0.450	0.440	0.070	0.050	0.015
ISRAEL	0.590	0.840	0.130	0.200	0.110	0.670	0.030	0.020
JAPAN	0.480	0.480	0.200	0.200	0.070	0.050	0.010	0.001
KOREA	0.690	0.630	0.490	0.380	0.590	0.070	0.030	0.027
NETHERLANDS	0.610	0.890	0.730	0.490	0.480	0.040	0.020	0.011
SPAIN	0.740	0.910	0.540	0.210	0.470	0.060	0.020	0.016
SWEDEN	0.620	0.870	0.390	0.290	0.340	0.040	0.160	0.019
SWITZERLAND	0.620	0.800	0.490	0.370	0.430	0.050	0.070	0.008
Total	**0.620**	**0.820**	**0.380**	**0.340**	**0.330**	**0.110**	**0.040**	**0.017**

tax income quintiles were estimated for each country, then responses from the survey income question were used to fill the quotas. When quotas were filled, respondents with these characteristics were stopped from completing the questionnaire. More details on the questionnaire design, respondent targeting and quota sampling are provided in (Ameli and Brandt, 2015; OECD, 2011).

The study uses as dependent variables different forms of households' self – reported environmentally friendly technology adoption collected as part of OECD, 2011: Households were asked whether they undertake the following activities between 2001 and 2011:

Bought appliances that received a top rating in terms of energy efficiency (Appl) Bought low energy light bulbs (Bulb).

Installed energy efficient windows i.e double or triple glazing (Windows).

Engaged in thermal insulation of walls or roof (Thrm)

Installed heat thermostat (Heat)

Installed solar panels for electricity or hot water (Solar)

Installed ground source heat Pump (Pump)

Installed wind turbine for electricity (Wind)

The variables; Appl, Bulb, Windows, Thrm, Heat, Solar, Pump and Wind representing the various types of environmentally friendly energy investments and considered as binary outcomes are the dependent variables of the equations defining multivariate probit models. Table 1 summarizes the dependent variables by countries surveyed. The following sub-sections describe the main independent variables used in the study.

Socio-economic characteristics

Available Socio-economic variables in the household dataset include the respondent's age (Age), gender (Male), size of household (HHsize), the number of years of education after high school (Education), annual net household income (Income) and employment status of households' head created as dummy variable (Professional). There is a dummy variable that takes a value of 1 for households stating that they cannot cope with their current income (Nocope). Studies suggest that individuals with higher income and education tend to be more likely to adopt energy efficient technologies, while the influence of age and gender is less clear (Ameli and Brandt, 2015). Income might be a relevant variable considering that investment cost seems to be one of the major barriers to investing in energy efficiency. However, income would only be expected to influence investment decisions if lower-income households are credit-constrained or if their ability to assess the profitability of investments is less well developed than for higher income households. Otherwise, lower- income households would be able to identify profitable investments like higher-income households and they would be able to obtain a credit to invest. At the same time, a variable that captures the respondent's education should capture any difference in the ability to assess the profitability of investments across households better than an income variable. Thus, if income and/or education is significant predictor of adoption, it shows evidence of irrational consumer decision and is one of the tested hypotheses of the current study.

Approximately, the average annual household net income in the dataset is 37 868 USD with considerable differences in means across countries. Chilean Households declared the lowest average annual income (13 585 USD), while the highest was declared by households living in Switzerland (62 278 USD). 36% of household's experience difficulty in coping with their salary and as expected, there are more than average number of households expressing this difficulty in Chile (43.6%), France (43.8%) and Israel (42.8%). Chile and Israel are the two main countries with a highest percentage of professionals as household heads, 36% and 31.8% respectively, while France is (11.5%). A number of respondents in the sample has at least university education as the average length of education after high school is 3.5years.

Dwelling Characteristics

Questions about characteristics of dwellings were asked, such as home-ownership versus rental (Owner), dwelling type (Detached House), number of years lived in the primary residence (Tenure) and whether households live in a rural or urban area (Rural). Controlling for home ownership provides evidence on the frequently cited owner-effect. In most countries, investment incentives for owners who rent out their apartments are weak, since in general it would be the tenant who benefits from any energy savings. At the same time, tenants may not be allowed to invest, but even if they are, their incentives to do so are probably weaker than those of owners who live in their home, as tenants are more likely to move before their investment pays off. Many empirical studies have confirmed the presence of an owner-effect (Tovar, 2012; Davies, 2010).

The number of years already spent by households in their house may also matter. Some investments may be more likely to be made as a household moves in to a dwelling, since this is usually a good moment for home improvements. In other cases, the length of time that households have already spent in their home may be indicative of their attachment to it and hence a longer tenure may increase the likelihood to invest. The floor size (Floor_size) of household's home, whether households live in a rural area and/or have a detached house may be indicators of space availability (Michelsen and Madlener 2012), as living in larger homes may be relevant for investing in energy technologies requiring more space.

A good number of respondents (63%) in the dataset own their residence and more than half of the investigated households live in a detached house (53%). Highest rates of ownership are observed in Spain (79.8%), Korea (69.8%) and the Netherlands (68%), while relatively many households live in a detached house in Australia (82.6%), Chile (77%) and the Netherlands (74%). On average, households have lived for approximately 13 years in their primary residence, although average tenure is longer in Japan (18 years).

Attitudes and behaviour towards the environment

To reflect the role of social context, households' beliefs, attitudes and behaviours regarding the environment, some dummy variables were created. These include a dummy variable for households that participate in a non-governmental organisation (NGO) and another one for those that are specifically in an environmental NGO (Env NGO). There is a dummy variable for people who rated the environment as the most pressing concern (Envtopcon) and another one for those who instead rated the economy as the most pressing concern (Ecotopcon) Respondents were asked questions regarding their willingness to make sacrifices to protect the environment, their assessment of the need to do so and the role of technology in solving environmental problems. Depending on their answers to those questions households were grouped in three clusters i) those who are the environmentally motivated and are willing to make sacrifices in their lifestyle to solve environmental problems (Altruists), ii) those who are not willing to make much effort to solve environmental problems because they believe that the climate problems are often exaggerated (Sceptics), and iii) the third group believe in the reality of climate problem but that technological innovations are key to solving them (Green Growthers) (see OECD, 2011)45% of the respondents are classified as Altruists (Altruists) with variations across countries, 65% of respondents are classified as "Altruists" in Israel and around 55% in France and Sweden. On the other hand, on average across countries 35% of respondents are sceptical (Skeptics) about the existence of environmental problems. Japan showed the highest level of scepticism (45%), while Chile showed the lowest level (18.8%).

In most countries, membership in non-governmental organisation is quite popular; more than 50% of respondents are engaged in some non-governmental organisation (NGO). Only in Japan is this share much lower, just above 30%. On average across countries around 10% of respondents are engaged in an environmental NGO (Env_NGO).

To investigate cost bias hypothesis, a dummy is constructed in line with Ameli and Brandt, (2015) to capture whether households give higher weight to investment costs than to future energy savings. In principle, individuals should be indifferent between lower investment costs and higher energy prices, since these factors have an equivalent impact on the net present value of energy saving investments, the sum of forecasted discounted energy savings minus the upfront investment cost. When the rating given to initial investment cost exceeds the rating for future energy prices by three points on the scale, respondents are considered as having a bias towards initial investment costs and the dummy variable takes a value of 1.

Households Perception of Quantity and Costs of Energy Use

To measure this perception, questions regarding households' knowledge about their energy consumption/spending and method of payment of energy bills were used to create dummy variables. During the survey, respondents were asked to get hold of their energy bills before answering the survey, but only about 55% were able to provide information about their energy spending. (Ebill_known) captures if household was able to provide this information or not) on average across

Table 2. Summary statistics for the independent variables.

Variable	Obs	Mean	St. Deviation	Min	Max
Socio-economic characteristics					
INCOME ($)	8, 765	37868.04	24681.14	2304.525	159160.6
EDUCATION (years after high school)	8, 765	3.500492	3.152784	0	12
AGE (years)	8, 765	42.01352	13.7693	18	69
HOUSEHOLD SIZE	8, 765	3	1.416855	1	6
MARRIED	8, 765	0.6361252		0	1
MALE	8, 765	0.4913949		0	1
NOCOPE	8, 765	0.3619079		0	1
COST BIAS	8, 765	0.3631372		0	1
SHARE OF NON-GRADUATE	8, 765	0.0960471	0.2182375	0	1
SHARE OF GRADUATE	8, 765	0.2209009	0.2778962	0	1
SHARE OF UNDER 18	8, 765	.1538248	0.2155072	0	0.8333333
SHARE OF OVER_55	8, 765	0.1203204	0.2503451	0	1
Beliefs, Attitudes and Behaviour					
BEHAVIOUR INDEX	8, 765	7.427157	1.864599	0	10
ECOTOPCON |MATERIALISM	8, 765	0.352811		0	1
ENVTOPCON	8, 765	0.1589084		0	1
NGO	8, 765	0.517784		0	1
ENV NGO	8, 765	0.1070316		0	1
SKEPTICS	8, 765	0.3531388		0	1
Dwelling Characteristics					
FLOOR SIZE (SQUARE MILES)	8, 765	109.8426	59.85085	32.13473	334.1077
DETACHED HOUSE	8, 765	0.5360597		0	1
OWNER	8, 765	0.6306343		0	1
TENURE	8, 765	12.85756	13.67766	1	40
RURAL	8, 765	0.3445337		0	1
Perception Energy use knowledge					
ELECTRIC BILL KNOWN	8, 765	0.5518767		0	1
QUANTITY OF ELECTRICITY KNOWN	8, 765	0.1902967		0	1
PAY AS YOU USE	8, 765	0.9116538		0	1

Note: Standard Deviations are not calculated for dummy variables

countries while (Kwatt_known) captures if households were able to provide energy use information by volume.

Regarding prudence in energy use (curtailment), the “behaviour index” variable captures whether respondents perform certain energy conservation actions regularly, such as turning off the lights when leaving the room, cutting down on heating/airconditioning to limit energy consumption, running full loads when using the washing machines, washing clothes using cold rather than warm/hot water, switching off the standby mode of appliances and air dry laundry rather than using a clothes dryer. The behaviour index ranges from 0 to 10, where higher values indicate that households perform several of the sections regularly. The data suggest that households perform quite regularly energy conservation actions, as on average across countries the behaviour index takes values around 7. Lower values of the index are observed in Sweden (5.55) and Switzerland (6.82), while higher values are observed in Chile (8.32) and Spain (8.39). Table 2 summaries the dependent variables:

EMPIRICAL METHODOLOGY AND RESULTS

A Model of Joint Investment: Energy Efficiency and Renewable Energy Technologies

In principle, households could invest jointly in energy efficiency and renewable energy technologies. Empirical modelling of such joint investment follows from Ekholm et al. (2010) and Dato (2014) which describes the consumer energy investment problem as utility maximization under budget constraint. Assuming that utility derived from energy consumption is separable from utility due to other forms of consumptions, households may set aside energy budget specific for solving households' energy consumption problems. The energy budget holds the income that a household devotes to energy service demand and any grants or other forms of financial support the household may receive for energy procurement. It could be assumed that the households would prefer to invest in energy efficiency in order to minimize energy expenditure and in renewable energy to satisfy private affection for the environment. The affection for the environment unlike materialistic consumption is intrinsically motivated and may receive less than optimum budgetary allocation from the household's budget (Welsh and Kuhling, 2010). The energy budget constraint expresses the limited investment capacity of the household.

Aside energy, other realms of consumption compete for households' income. Furthermore, for households that have environmental affection, energy efficiency investments compete with renewable energy investment for the households' energy budget. Therefore, there may be substitutability rather than complementarity between energy efficiency and renewable investments. However, apart from private utility from income and/or other forms of consumption, households may also derive private affective utility by virtue of pro- environmental energy consumption. In this case, investment in renewable energy complements energy efficiency investment. Two opposing forces therefore, drive households' investments in environmentally friendly energy technologies. That is, the forces of income or other forms of consumption and the forces of environmental affection. Thus, under multi variant estimation framework, the sign of the correlation coefficients suggests the nature of relationship existing between the choice dimensions.

Econometric Estimation

To study household choices of the six pro-environmental investments, a corresponding number of binary equations were generated. Every type of pro-environmental investment corresponds to binary choice equation and households' choices are modeled using correlations among the equations' disturbances. If the correlation coefficients are significantly different from zero, then meaningful relationships are established among the various choices. A significant positive relationship suggests complementary choices while significant negative relationship suggests substitute choices. Since, MVP model is used in this case, the sign of the correlation coefficients depends on the data rather than specified apriori. The multivariate model specifies households' choices of the different types of clean energy investments on some function of covariates, allowing for simultaneity of investment choices. As households could adopt more than one type of energy investment simultaneously, another advantage of this model is that patterns of household's investments in as many investment types as possible is estimated empirically on the basis of the data. No restriction in this pattern is needed under the multivariate model. Relations among the different choices of households' investments are modelled through correlation parameters that are assumed arbitrary and have to be estimated (Calia and Farrante, 2013). These correlations tell us how different types of clean energy investments are combined by households and if there are unobserved factors, besides those explicitly considered, that simultaneously affect different choices of investment. This reflects the traditional household's utility maximization over a basket of goods under a budget constraint.

The MVP is adopted similar to Calia and farrante (2013), specifying a joint multivariate normal distribution for the error terms. Formally considering M clean energy investments for each observation, there are M equations each describing a latent dependent variable to which there is a corresponding observed binary outcome. The model is written with suppressed subscripts as follows;

$$\gamma_m^* = \beta_m^{'} X_m + \mathcal{E}_m m = 1, \ldots, M$$
$$\gamma_m = 1 \quad if \gamma_m^* > 0 \; and \; 0 \; otherwise$$
$$Equation\ 1$$

Where $\mathbf{X}_{\boldsymbol{m}}$ is a vector of $\boldsymbol{P}$ covariates for the $\boldsymbol{m}$-the equation ($\boldsymbol{m}$ = 1, …, $\boldsymbol{M}$), $\boldsymbol{\beta'}_{\mathbf{m}}$ is the corresponding vector of parameters and $\boldsymbol{\varepsilon}_{\mathbf{m}}$ is a vector of error terms corresponding to each equation of the model assumed to be jointly normally distributed with means of 0 and variance of 1 and correlation coefficients; ρ.

The multivariate probit model considers six potentially related binary outcomes. The relatedness exists beyond conditioning on regressors and occurs through correlation of the errors that appear in the index-function model formulation of the binary outcomes. In general, the multivariate probit models consider two or more equations of binary outcomes and is the multinomial analogue of seemingly unrelated regression model with the dependent variables in form of binary outcomes.

The observed outcomes are:

$$Y_i = \begin{cases} 1 \; if Y_i^* > 0 \\ 0 \; if Y_i^* \leq 0 \end{cases} i = 1, 2, 3 \ldots M \boldsymbol{Equation 2}$$

The model collapses to univariate probit models for the separate dependent variables if εs are identically and independently distributed or if ρequals zero. The model may be estimated by means of simulated maximum likelihood (SML) using the Geweke-Hajivassiliou-Keane (GHK) simulator that results in unbiased estimates of the multivariate normal probabilities (see Cappellari and Jenkins2003).

ESTIMATIONRESULTS

Two sets of estimations were conducted: In the first

Table 3. Ranking pro-environmental investments.

Description	Investment Rank
Household invests in neither Energy efficiency nor renewable energy	0
Household Invests in only one of either Energy efficiency or renewable energy	1
Household invests in more than one of Energy efficiency and at most one renewable	2
Household invests in more than one renewable energy technology only	3
Household obtains a mixture of both dimensions involving more than one renewable	4

Table 4. Technology specific estimates: energy efficiency.

	WINDOWS	APPL	THRM
LOG_INCOME	-0.0093*	0.0081	0.0056
EDUCATION	0.0010	-0.0071	0.0026
MALE	0.0318	0.0359	0.0200
MARRIED	0.1170**	0.2149***	0.1260***
NOCOPE	-0.0881**	-0.0222	-0.0860**
AGE	0.0045**	-0.0027	-0.0004
HHSIZE	0.0215	0.0010	0.0229
SHARE AGE55	0.1059	0.1067	0.3289***
BEHAVIOUR_INDEX	0.0554***	0.0789***	0.0789***
NGO	0.1247***	0.1945***	0.1382***
ENV_NGO	0.0201	0.0851	0.0775
ECOTOPCON	-0.0224	0.0222	-0.0335
ENVTOPCON	0.0263	0.0206	0.0196
SKEPTICS	-0.0551	-0.0485	0.1028***
LOG_FLOOR	0.2238***	0.1695***	0.2891***
OWNER	0.4042***	0.2293***	0.3903***
DHOUSE	0.0250	0.0630	0.2616***
TENURE	-0.0029*	0.0021	-0.0060***
RURAL	0.0564	0.0117	0.1507***
PAY AS YOU USE	0.1402*	0.1532**	0.0652
EBILL_KNOWN	0.0426	0.0640	0.0181
KWATT_KNOWN	0.0034	0.1656***	0.0276
Sample Size	**8,765**	**8,765**	**8,765**
Waldchi2 (22) = 3,832.48 [Six EquationModel]			

*p <0.05; **p <0.01; ***p <0.001.

estimation, determinants of specific choices were estimated using MVP model (Tables 4 and 5). Along with this, cross correlation coefficients among the various equations were measured (Table 6). The objective of the second estimation is to identify the determinants of joint investments in the two dimensions of pro- environmental investments: Energy efficiency and renewable energy technologies. Investments were ranked according to how they theoretically affect the environment as shown in table 3; Ordered probit estimation procedure was used to identify correlates of being in the topmost category.

Technology SpecificResults

Tables 4 and 5 report the results. From table 4, determinants of investments in energy efficiency dimension are marital status (married), income constraint (nocope), energy use prudence (behavior index), social engagement (NGO), space availability (Floorsize), occupancy status (Onwer), length of stay in residence (tenure) and metering method (Pay as you use). In effect, the results confirm popular theoretical predictions: income constrained households are less likely to invest in sustainable energy use and households who are prudent in their energy use tend to seek more opportunities to enhance their energy conservation. There is the lemon problem since those who live in owned houses are more likely than renters to invest in energy efficiency. There is also space factor since investment in energy efficiency increases in floor size of the living home. Variation in

Table 5. Technology specific estimates: renewable energy.

	PUMP	WIND	SOLAR
LOG_INCOME	0.0042	0.0012	0.0026
EDUCATION	0.0228	0.0144	0.0214*
MALE	-0.0200	0.0709	0.1899
MARRIED	0.0618	0.0679	-0.0456
NOCOPE	0.0248	0.0386	-0.0799
AGE	-0.0113***	-0.0136***	-0.0076**
HHSIZE	0.0516	0.0435	0.0732***
SHARE AGE55	0.3710	0.6198**	0.3703**
BEHAVIOUR INDEX	0.0342*	0.0442*	0.0614***
NGO	0.1241*	0.1094	0.2144***
ENV_NGO	0.1911**	0.3867***	0.2999***
ECOTOPCON	-0.0842	-0.0027	-0.0224
ENVTOPCON	-0.0993	0.1147	-0.0382
SKEPTICS	0.2869**	0.2191**	-0.0029
LOG_FLOOR	0.1755**	0.1519*	0.1491***
OWNER	0.2088**	0.1253	0.3050***
DHOUSE	0.0616	-0.1325	0.1645**
TENURE	-0.0001	0.0031	-0.0014
RURAL	0.0325	-0.2518*	-0.1033*
Pay_AS_YOU_USE	-0.2442**	-0.1359	0.0342
EBILL_KNOWN	-0.0354	-0.1742*	-0.0452
KWATT_KNOWN	-0.0292	0.0547	0.2123***
Sample size	**7,861**	**7,861**	**7,861**
Wald chi2(22)	= 3,832.48 [Six Equation Model]		

*p <0.05; **p <0.01; ***p <0.001.

Table 6. Cross correlation coefficients.

EFFICIENCY × EFFICIENCY		
rho21	EFFICIENT WINDOWS ↔ EFFICIENT APPLIANCES	0.2157***
rho31	EFFICIENT WINDOWS ↔ THRM INSULATION	0.5833***
rho32	EFFICIENT APPLIANCES ↔THRM INSULATION	0.2682***
RENEWABLE × RENEWABLE		
rho54	WIND TURBINE ↔ GROUND SOURCE HEAT PUMP	0.7882***
rho64	GROUND SOURCE HEAT PUMP ↔ SOLAR PANEL	0.5013***
rho65	WIND TURBINE ↔ SOLAR PANEL	0.5326***
EFFICIENCY × RENEWABLE		
rho43	THRM INSULATION ↔ GROUND SOURCE HEAT PUMP	0.3069***
rho51	EFFICIENT WINDOWS ↔ WIND TURBINE	0.3504***
rho52	EFFICIENT APPLIANCES ↔ WIND TURBINE	0.1951***
rho53	THRM INSULATION ↔ WIND TURBINE	0.3766***
rho61	EFFICIENT WINDOWS ↔ SOLAR PANEL	0.2639***
rho62	EFFICIENT APPLIANCES ↔ SOLAR PANEL	0.1956***
rho63	THRM INSULATION ↔ SOLAR PANEL	0.3489***

*p <0.05; **p <0.01; ***p <0.001.

energy bill payment matters as households who their bills according to what the use as opposed to flat rate are more likely to invest in energy efficiency. The tenure effect aligns with the result of Tovar (2012). Households in this sample prefer to install energy efficiency measure earlier rather than later in their occupancy of the living home. Income of households, age of reference person, knowledge of volume of energy consumed at home, living in detached houses or in rural areas only matter for selected technologies within the dimension. However, general social orientation matters for energy efficiency technologies whereas environment specific social orientation (Env NGO) does not matter for any equation in the energy efficiency dimension.

With respect to table 5 determinants of investment in renewable energy are Age, elders popular at home (share of age 55), energy use prudence (behaviour index), general and specific social orientation (NGO and Env_NGO). In general, similar factors predict investments in both dimensions. However, important differences recorded in respect to age and social orientation. Investors in renewable energy technologies are generally younger than investors in energy efficiency measures and tend to associate with both general and specific NGOs. There is further heterogeneity separating the energy efficiency and the renewable technologies adopters: adopters of the energy efficiency technologies are likely to express difficulty coping with their current income but this is not observed for renewable energy adopters. That is to say that income constraints are operative with respect to energy efficiency investment but not with respect to renewable energy investment. This may reflect the effect of subsidies on investments since renewable energy technologies are more likely to be subsidized than energy efficiency investment (OECD, 2011).

Relationship between choice across the dimensions

The correlation coefficient of the six equations in table 6 suggest positive relationships among all the investment choices. Tests of significance was conducted on the correlation matrix and all correlation coefficients were found to be statistically greater than zero. Although greater correlation is found within dimension, across dimensions the correlation is not positive nor negative. This suggest a complementary relationship between energy efficiency investments and renewable energy investments. Households seem to engage in energy efficiency to save money and in renewable energy to satisfy intrinsic environmental affection.

Table 7 further explores the determinants of these relationships and identified education in terms of number of years of schooling after high school and in terms of the share of graduates in the home as contributory factors. There equally seem to be economies of scale among the factors: household size, share of children (Share under 18) are positively associated with joint investment. On the other hand, tenure is negatively associated with joint investment. Owners of their living home are less likely to jointly invest in energy efficiency and renewable energy. Method of energy bill payment does not matter as well.

CONCLUSION AND POLICY RECOMMENDATIONS

This study sets out to identify the factors that determine households' joint adoption of energy efficiency and renewable energy technologies. In the process, technology specific determinants were estimated and the results show that the two dimensions of pro-environmental investment are determined by different sets of covariates. Income constraints affect investments in the energy efficiency dimension but not the renewable energy dimension. The study found evidence for split incentives between home owners and renters and negative tenure effect for both dimensions. Space availability in the living home matters generally for adoption of environmentally friendly energy behaviours. Payment of energy bills according to use matters only for energy efficiency while households' association with environmental NGO only matters for renewable energy investment.

A complementary relationship between households' choices of investment in energy efficiency and renewable energy technologies is suggested by this work: all correlation coefficients of the multivariate energy investment model were positive and significant with highest coefficient observed within rather than across dimensions. Determinants of the joint investments was found to relate to education, economies of scale and social engagement in the form of association with non-Governmental organizations. Owners are less likely than renters to jointly invest in both dimensions even though owners are more likely to invest in energy efficiency measures. Joint investments in both dimensions decrease in length of staying the living home.

This study suggests that when it comes to promoting energy efficiency technologies, subsidization policies could be effective since it was found that income constraint plays significant role in households' adoption of these set of technologies. Therefore, Subsidization policies targeted at energy efficiency technologies should be effective. However, such policies if targeted at renewable or low penetrated energy efficiency investments may not be effective as they will be taken up by consumers who are not subject to income constraint.

Apart from economic incentives, since participation in NGO is positively associated with behaviour in all dimensions, raising awareness through informal channels could have effects on all the technologies irrespective of whether the technology is energy efficiency or renewable option.

Finally, the correlation of errors in any pair of the equations, in particular between energy efficiency and renewable energy technologies are significant and positive. This suggests that investment in one environmentally friendly energy technology increases the likeliness of investing in another. Thus the interaction between households' choices of environmentally friendly energy technologies should play a role in policy design. More effective policies should explore the knowledge that certain environmentally friendly energy investment can lead to heightened tendency to adopt other forms of environmentally friendly energy behaviour. Specifically, positive correlations between pairs of energy efficiency

Table 7. Correlates of joint investment.

VARIABLES	Investment Rank
LOG_INCOME	0.00510
	(0.00367)
EDUCATION	0.0152***
	(0.00587)
MALE	-0.0610**
	(0.0256)
MARRIED	0.00729
	(0.0317)
NOCOPE	0.0194
	(0.0274)
SHARE GRADUATE	0.178**
	(0.0690)
AGE	-0.000658
	(0.00144)
HHSIZE	0.0287**
	(0.0145)
SHARE UNDER_18	-0.134*
	(0.0724)
SHARE AGE55	0.0168
	(0.0727)
BEHAVIOUR_INDEX	0.0475***
	(0.00750)
NGO	0.149***
	(0.0272)
ENV_NGO	0.0765*
	(0.0427)
LOG_FLOOR	0.0494
	(0.0303)
OWNER	-0.408***
	(0.0305)
DHOUSE	-0.342
	(0.00142)
TENURE	-0.00421***
	(0.00106)
RURAL	-0.0306
	(0.0291)
PAY AS YOU USE	-0.0755
	(0.0507)
KWATT_KNOWN	0.0903***
	(0.0329)
Constant cut1	-1.811***
	(0.165)
Constant cut2	-0.202*
	(0.164)
Constant cut3	0.297*
	(0.164)
Observations	9,784
Pseudo R2	0.1064
Country Dummies	Included

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

and renewable technologies suggest complementarity of the two forms of environmental behavior and should be explored in policies design.

Most previous models of environmental behaviour do not explore these correlations. Such models are likely inefficient and lacking in essential information. Future research should focus on incorporating the nature of relationships among different forms of environmental behaviour in the behavioural models.

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APPENDIX

Appendix A. Country effects on technologies adoption.

	WINDOWS	APPL	THRM	PUMP	WIND	SOLAR
AUS	-1.2555***	0.0089	0.2093**	-0.1193	0.3789*	0.5789***
CAN	0.0069	0.0268	-0.1751*	-0.1196	0.2101	-0.4474***
CHE	-0.0360	-0.1863**	-0.1821*	0.4561***	-0.2699	-0.1256
CHL	-1.0360***	-0.8287***	-0.3760***	-0.73811***	0.0052	-0.8388***
ESP	-0.0158	0.0214	-0.6808***	-0.255	-0.1287	-0.1511
FRA	0.1669*	0.0657	-0.0607	0.1830	-0.0142	-0.1050
ISR	-1.0317***	-0.2225***	-0.5013***	-0.0788	-0.0154	1.9455***
JPN	-0.8022***	-0.5244***	-0.6022***	-0.7463***	-1.0694**	-0.3527**
NLD	0.5705***	-0.2308***	0.1299	-0.3566*	-0.2786	-0.236*
SWE	-0.2244**	-0.1248	-0.3278***	1.0185***	0.1639	-0.3421**

*p <0.05; **p <0.01; ***p <0.001.