Residential Energy-Efficient Technology Adoption, Energy Conservation, Knowledge, and Attitudes: An Analysis for European Countries

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Abstract:

Relationships between a number of measures of household behavior with respect to energy are estimated using a unique dataset of approximately 5,000 households in ten EU countries and Norway. The results indicate that home knowledge of energy consumption and energy-efficient technology options is associated with household use of energy conservation practices, but not with household adoption of energy-efficient technologies. Household characteristics also influence household behavior with respect to energy. For example, younger household cohorts are more likely to adopt energy-efficient technologies and energy conservation practices than are households composed primarily of older adults. Similarly, the stated importance of energy conservation for financial and environmental reasons differs with household age structure. Households with younger children place primary importance on energy savings for environmental reasons, while households with a high share of elderly members place more importance on financial savings. Education also influences the stated importance of energy conservation, as low education households reveal they are primarily motivated to save electricity for financial reasons and high education households indicate they are motivated by environmental concerns. Significant country differences also exist. Households in transitioning Eastern European countries generally show lower levels of energy-efficient technology adoption compared to Western European countries, but show a strong propensity to employ energy-conservation practices in the home. Eastern European households also generally place less importance on saving electricity for environmental reasons. Overall, the results suggest that EU policies to promote residential energy-efficient technology adoption and household energy conservation must be sensitive to both cross-country and intra-county variations in household behavior with respect to energy use.

Keywords: Household energy-efficiency**;** technology adoption; energy conservation

1. Introduction

The EU has set an indicative target for energy efficiency as part of the climate and energy package that includes binding 2020 EU27 targets for greenhouse gas emissions and renewable energy use (European Commission 2008, European Council 2006). The EU seems on track to achieve required 20 percent reductions in greenhouse gas emissions in 2020 compared to 1990 levels, along with 20 percent renewable energy use in total final energy consumption. However, the energy efficiency target of 20 percent energy savings in 2020 compared to business-as-usual development may be missed without further measures (COM(2008) 772 final). Efficiency gains in the household sector, which accounts for about 25 percent of total final energy consumption and 29 percent of total electricity use in the EU27 (Bertoldi and Atanasiu 2009), are expected to be a key factor in determining whether or not the EU meets its efficiency targets. According to the European Council Action Plan for Energy Efficiency (European Council 2006) residential energy-savings of 27 percent may be achieved compared to expected baseline growth by 2020 through the adoption of cost-efficient residential energy efficient technologies and conservation practices. In a more recent study, Fraunhofer ISI et al. (2009) estimate that the residential sector may cost-effectively save about 19 percent of final energy compared to the baseline in 2020 with additional policies to overcome barriers to adoption of existing technologies. The bulk of these savings will come from improved thermal insulation, but 7 percent of energy savings are expected to accrue from the adoption of energy efficient household appliances (including lighting). Additional policy measures to enhance adoption can increase the energy efficient household appliance contribution to final energy savings to about 17 percent compared to business as usual in 2020.

In general, residential energy policies can be employed to both enhance the uptake of improved energy conservation practices (e.g. switching off lights when leaving a room, adjust indoor temperature at night, reduce heat in unused rooms, only use dishwasher and washing machines at full load, put lid on pots) and increase for adoption of energy efficient technologies (e.g. insulation of outer walls, attic, window glazing; energy-efficient heating system; purchase energy efficient household appliances, office equipment or light bulbs). The formulation of effective and well targeted residential energy policies to increase both conservation and technology adoption must be based on a sound understanding of how technology adoption, conservation practices, energy use knowledge, and attitudes towards energy conservation are associated with household characteristics. In a diverse regional organization like the EU, it is also essential to identify country-specific differences in energy-saving technology adoption and energy conservation in order to generate an appropriate combination of common and country-specific policies.

This paper employs a unique dataset of almost 5,000 households from eleven European countries (ten EU countries and Norway) to identify differences in residential energy efficient technology adoption and energy conservation behavior due to household characteristics and country of residence. Relationships between household characteristics and household knowledge of energy use and energy-saving technologies and household attitudes towards energy conservation are also explored with the dataset. The research is, to our knowledge, the first attempt to analyze residential energy conservation technologies, behavior, and attitudes jointly for a broad cross-section of European countries.

The remainder of the paper is organized as follow. After a review of the literature in section two, section three lays out the empirical specification of the model. Section four provides a description of the data. Results are presented in section five and the final section discusses the main findings and concludes.

2. Literature overview

Household level analyses on the adoption of energy efficient technologies and conservation practices are rather scarce and are concentrated on the US, Canada, and several individual EU countries. Dillman et al. (1983) and Black et al. (1985) examine (primarily thermal) energy efficiency investments and adjustments in behaviour using surveys of the Western States of the US and Massachusetts, respectively, while Walsh (1989) and Long (1993) focus on the adoption of thermal energy measures for the entire US. Curtis et al. (1984) analyze technology adoption and behavioral practices aimed at reducing household thermal energy and electricity use in Regina (Canadian Province of Saskatchewan) and Fergusen (1993) analyses the adoption of retrofitting measures for all of Canada. Brechling and Smith (1994) and Caird et al. (2008) explore insulation, heat generation and lighting technologies in UK households. Barr et al. (2005) use data on selected technological measures and conservation practices related to household thermal energy and electricity use for the UK county of Devon. Poortinga et al. (2003, 2004) include an extensive list of technological measures and behavioral practices associated with thermal energy and power use in the Netherlands, while Scott (1997) focuses on several technology measures (attic and hot water cylinder insulation and lighting) in a survey of Irish households. For Germany, Mills and Schleich (2010a) and Mills and Schleich (2010b) explore the adoption of energy-efficient household appliances and of compact fluorescent light bulbs (CFLs), respectively. Finally, for Sweden Linden et al. (2006) consider a set of behavioral practices, Mahapatra and Gustafsson (2008) analyze the adoption of heating systems, while Nair et al. (2010) consider several thermal energy investments as well as behavioral practices related to electricity and thermal energy use.

Most studies find that adoption of energy efficient measures and behavioral practices are typically associated with costs (for investments and energy use), habits, and routines, which differ across measures, households and regions. Curtis et al. (1984) were among the first to point out that energy-savings measures may be distinguished in low-cost or no-cost measures which do not involve capital investment but rather behavioural change and high-cost measures which require capital investment and involve technical changes in the residence. Similarly, from a behavioural perspective it is much easier to change a singular investment decision such as purchasing a CFL than to change daily behaviour such as switching off lights after leaving a room (e.g. Gardner and Stern 1996). Also, while energy savings resulting from technology adoption tend to have long run effects, behavioural measures may only have transitory effects (e.g. Abrahamse et al. 2005). Barr, Gilg and Ford (2005) also distinguish explicitly between habitual behaviour and technology adoption and stress that energy savings behaviour needs to be considered within the broader context of environmental behaviour. Adoption of energy efficient technologies and conservation measures is usually associated with reduced emissions of greenhouse gases and other pollutants that benefit others without compensating the energy savers. In this context, motives for energy savers' provision of a public good include altruism, empathy, the 'warm glow of giving' (Andreoni 1990) and prestige (Harbaugh 1998).

Studies on the adoption of energy efficient measures in households are typically based on different, partially overlapping concepts from economics (including behavioral economics), psychology and sociology. Insights from the psychology and sociology literature are employed to analyze the impact of psychological variables such as values, beliefs, or attitudes towards energy conservation as well as the impact of social norms shared by relevant groups on energy efficiency activities (Gardner and Stern 1996). The thrust of this literature suggests that attitudes towards energy conservation or environmental motivation in general may at best explain a modest share of the variation in household energy consumption or adoption of energy savings measures (e.g. Viklund 2004, Sjöberg and Engelberg 2005, OECD 2008). Environmental behaviour is not only driven by motivational factors, but also determined by contextual factors, including opportunities, individual abilities, status, comfort, and effort (Poortinga 2004, Stern 2000). In particular, attitudes do not directly determine behavior. Instead they affect intentions which in turn form people's actions. According to Ajzen and Fishbein (1980, p. 239) intentions are not only influenced by attitudes but also by social pressure and perceived behavioural control. In other words, attitudes towards environment may not necessarily lead to good intentions, and stated good intentions may not necessarily lead to good actions. Social norms, lack of information about the implications of alternative actions on the environment, or institutional and economic factors may act as barriers towards actual implementation (Van Raaij and Verhallen 1983). Kammerer (2009) emphasizes the importance of additional customer benefits as a key factor in the demand for "green" products. These additional benefits include energy (and other) cost savings, improved product quality (durability and reliability) or improved repair, upgrade, and disposal possibilities.

Based on the empirical literature, factors influencing energy saving activities may generally be categorized as characteristics of the household (education, income, number of children, age, renter or owner), characteristics of the residence (multi-family home, size), characteristics of the measure (behavioral or technological, costs, performance, energy use), economic factors (energy prices), availability and quality of information, weather and climate factors, and attitudes towards energy savings or towards the environment. We will briefly summarize the main findings of the literature, focusing more heavily on factors which are relevant for the subsequent empirical part of the paper.[1]

2.1. Education

Most studies suggest a positive correlation between education level and energy-saving activities, including the econometric analyses by Hirst and Goeltz (1982), Brechling and Smith (1994) or Scott (1997) for energy efficient technology adoption. Exceptions include Ferguson (1993) and Schleich and Mills (2010a). Among the reasons for a positive correlation are that education reduces the costs of information acquisition (Schultz, 1975). Alternatively, education as a long term investment may be correlated

[1] Nair et al. (2010), Brohmann et al. (2009) and Sardianou (2007) include recent surveys of the empirical literature on household energy saving behavior and Wilson and Dowlatabadi (2007) provide a conceptual overview from economics, psychology, sociology and innovation studies.

with a low household discount rate and, thus, be positively associated with energy-saving measures that require higher up front investment costs for energy cost savings that materialize over time. Attitudes towards the environment as well as social status, lifestyle (Lutzenhiser 1992, 1993, Weber and Perrels 2000), and belonging to a particular social milieu group approving of environmentally friendly behaviour (Reusswig et al. 2004) also tend to be positively related with education. Torgler and Garçia-Valiñas (2007, p. 538) cite several sources suggesting that higher education levels are associated with higher preferences for environmental conservation.

2.2. Age and Household Composition

The majority of empirical studies analyzing the household up take of energy efficiency measures and practices control for age (of the household head), but only a few studies account for household composition by age groups. Older household heads may be less likely to adopt energy efficient technologies because the expected rate of return is lower than for households with younger heads. Among others, this line of reasoning is supported by the findings of Curtis et al. (1984), Walsh (1989), Poortinga et al. (2003) and Mahapatra and Gustavsson (2008). On the other hand, younger households may be more likely to move and hence be less inclined to invest in energy efficiency improvements, in particular if these measures become an integral part of the built environment. Combining these perspectives, middle aged households should be most likely to adopt capital-intensive energy efficiency measures (e.g. Mills and Schleich, 2010a), particularly if the technologies are structurally linked to the building. For measures with low up-front costs (e.g. light bulbs) and for behavioral measures the expected impact of age is less clear. Lutzenhiser (2002) finds that older households are less likely to adapt behaviour while in Mills and Schleich (2010b) adoption intensity of energy efficient light bulbs increases at a declining rate with age. On the other hand, as suggested by Carlsson-Kanyama et al. (2005), younger households tend to prefer up-to-date technology, which is usually also more energy efficient. In sum, the relationship between age and the take-up of energy savings measures is likely to be nonlinear and technology specific.

Lower adoption of energy efficient technologies by elder households may also interact with the cohort's fewer years of formal education, and lower levels of information on energy savings measures. For example, survey results by Linden et al. (2006) for Sweden indicate that younger people have better knowledge about energy-efficient measures than older people. Clustering individuals into different types, the findings by Barr et al. (2005) for the UK, and by Painter et al. (1981) and by Ritchie et al. (1981) for the US suggest that "energy savers" are older. Addressing environmental concerns directly, the studies by Whitehead (1991) and by Carlsson and Johansson-Stenman (2000) – cited by Torgler and Garçia-Valiñas (2007) – found that willingness to pay for environmental protection decreases with age, arguably because a shorter expected remaining lifetime results in lower expected benefits from environmental preservation. Torgler and Garçia-Valiñas (2007) for Spain and Torgler et al. (2008) for 33 Western European countries also observe a negative correlation between age and environmental attitudes/preferences. Similarly, according to Howell and Laska (1992) younger people in the US are more concerned about the environment than older people. However, as Torgler and Garçia-Valiñas (2007) also point out, age effects need to be decomposed into a life cycle effect which stems from being in a particular stage of life, and into a cohort effect which results from belonging to a particular generation with generation-specific experiences, socialization, and economic conditions (e.g. "flower power generation" versus "baby boomers"). Thus, depending on the timing and the region of the survey, age may turn out to have quite different effects on households' adoption of energy-efficient measures. Young children in the household may also impact adoption, as parents may be more concerned about short and long run local and global environmental effects that will influence current and future wellbeing of their children. Dupont (2004) finds that the number of children is positively related to the adoption of energy-efficient technologies and conservation behavior, but Torgler et al. (2008) do not find children to generate a positive shift in parental preferences for environmental conservation.

2.3. Information

Households' information on energy consumption, conservation opportunities and the energy performance of technologies is expected to affect the adoption of energy-efficient technologies. Availability and quality of information about the levels and patterns of current energy consumption depends on the level of metering, the information content of utility bills, and households' willingness and ability to analyse this information. Similarly, households need to be aware of and able to evaluate energy efficiency opportunities (e.g. Schipper and Hawk 1991). For example Scott (1997) observes that household knowledge about energy savings potential is associated with higher take-up of energy efficient technologies. Typically, labelling schemes such as those implemented in the EU and US for household appliances are cost-effective measures to overcome barriers related to information and search costs, or to bounded rationality on the part of appliance purchasers (Sutherland 1991, Howarth et al. 2000). Evaluation studies based on aggregate observed data find that the existing energy labelling programs for household appliances in the US, the EU and Australia are effective in terms of energy and carbon reductions (e.g. Sanchez et al., 2008; Lane et al., 2007; Banerjee and Solomon, 2003; Schiellerup, 2002; Bertoldi, 1999; Waide, 2001; Waide, 1998). Sammer and Wüstenhagen (2006) conduct survey-based conjoint analyses to analyze consumers' stated choices for washing machines in Switzerland and observe that eco-labelling affects consumers' purchasing decisions. Mills and Schleich (2010a) find that socio-economic factors like higher education levels, higher income, larger households, and higher electricity prices are positively correlated with respondents' knowledge about the energy efficiency label of appliances. Similarly, Murry and Mills (2010) find in the US household characteristics have a greater impact on EnergyStar label awareness than on the uptake of EnergyStar appliances. As for the impact of information campaigns, Reiss and White (2008) observe that consumers respond to both energy prices and information campaigns to reduce energy consumption, although – consistent with the weak correlation between attitude and conservation efforts pointed out above – a survey by the OECD (2008) concludes that information campaigns are not as effective as expected. Households often ignore mass information, but are more likely to respond to well-targeted, direct information (Lutzenhiser 1993). In sum, information may improve the level and the quality of knowledge on energy conservation measures, but improved information need not necessarily result in energy conservation.

3. Empirical specification

This paper focuses on establishing the empirical relationship between household decision variables (adoption of energy efficient technologies, use of energy conservation practices in the home, knowledge of level of energy use and energy saving options, and preferences for energy savings for environmental and for financial reasons) and household characteristics and country specific effects.

Dependent Variable Measures

Household adoption of energy efficient technologies is characterized by two alternative measures. The first measure is an index of adoption of energy efficient "white" appliances (refrigerators, freezers, dishwashers, washing machines, and dryers), office equipment, and light bulbs generated by factor analysis. White appliances account for about 25 percent of residential electricity use in the EU27, lighting for 11 percent, and computers for about 3 percent (Bertoldi and Atanasiu 2009, p. 13f). In the EU all major white appliances are classified under a common energy labeling framework from most efficient (class A++) to least efficient (class-G). The index includes a measure of the energy class of the above mentioned major white appliances. Many households did not report appliance energy classes, either because the appliance was purchased before the rating system was implemented or because the energy class was not known by the respondent.[2] In these cases the energy class is recorded as a zero. However, separate indicator variables are also included in the factor analysis to indicate that the energy class of the appliance was not known. Adoption of energy efficient office technologies is measured as the purchase of EnergyStar labeled products. Adoption of the third technology type, energy efficient light bulbs, is simply measured as the household energy efficient compact fluorescent bulbs (CFLs) as a share of all bulbs in the residence.

The CFL share of all household bulbs is used as an alternative measure of energy efficient technology adoption. The sole CFL share measure has the advantage of simplicity. But, by the same token, CFL share is a less comprehensive measure of household adoption of energy efficient technologies.

A household knowledge index is also generated through factor analysis. The index is based on three indicators of household knowledge of energy use; if the household knows its annual electricity consumption, if the household correctly knows what the EnergyStar label stands for, and if the household knows that computer monitor screensavers do not save electricity.

Similarly, a household energy conservation index is generated through factor analysis based on six indicators of energy conservation practices in the home. These practices are 1) fully loading the washing machine every time; 2) cooking frequently with a pressure-cooker; 3) turning off the lights every time a room is vacated; 4) turning off the TV when it is not being watched; 5) setting energy saving features on the computer monitor; and 6) setting energy saving features on the computer desktop.

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[2] Implementing directives were published by the EU in 1994 for refrigerators, freezers and their combinations, in 1995 for washing machines, and in 1997 for dishwashers. In 2004, the labeling scheme for cold appliances was extended to A+ and A++ to account for substantial energy efficiency improvements in the highest energy efficiency category. Appendix table A.1 provides information on the dates that implementation directives became law in specific countries.

Household attitudes toward energy savings are captured through household indicators of the stated importance of energy savings for environmental (greenhouse gas reduction) reasons and financial reasons. Specifically, attitudes are measured by households indicating that they felt it was ‘most important’ to save electricity for that reason.

The covariates employed to establish relationships with the above indexes are driven largely by data availability. Education is measured for the most educated member of the household as a continuous scale on the range of no high-school, high-school, trade or vocational school, and university. Household composition is measured by the number of members less than 12 years of age, the number of members 13 to 18 years of age, the number of members 19 to 65 years of age, and the number of members over 65 years of age. Country specific effects are captured through country specific indicators for Belgium, Bulgaria, The Czech Republic, Denmark, France, Greece, Hungary, Norway, Portugal, and Romania, with Germany being the base country.

Relationships with continuous indexes are estimated via OLS regression models. Given the large number of observations with a response of zero, relationships with the CFL share of household light bulbs regression are estimated with a Tobit model. Similarly, relationships with discrete environmental attitude indicators are estimated with Probit models.

4. Data

The study dataset is generated from the Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe Project (REMODECE) survey conducted in eleven countries in 2007. All countries used a common survey instrument that was translated into the local language. The goal was to survey at least 500 households in each country. However, there was considerable variation in country data collection strategies. Belgium, The Czech Republic, Denmark, Norway, and Portugal relied primarily on on-line internet based surveys. Bulgaria and Germany relied primarily on mail surveys, while France used telephone interviews and Hungary and Romania used face-to-face interviews. Greece used a mixture of face-to-face, online, email, and mail surveys. Data are available from the project website at: http://www.isr.uc.pt/~remodece/. The overall sample contains 4,902 households.[3] The distribution of country sample sizes from the website data ranges from Romania with 622 households to France with 100 households.

Descriptive statistics for the variables employed in the study are presented in table 1. As expected, the means of all the dependent variables generated through factor analysis (buyind, knowledge, effindex) are zero. The cflshare variable indicates that the average share of household bulbs that are CFLs is 16.6 percent, with 43 percent of households having no CFL bulbs. For attitudes, 19.6 percent of households indicated that energy savings was most important for greenhouse gas reductions and 63.2 percent indicated that energy savings was most important for financial reasons.

5. Results

[3] Information on CFL bulb shares is missing for an additional 6 households, leaving sample sizes for the energy-efficient technology adoption measures of 4,896 households.

Regression results appear in table 2. The index for adoption of energy efficient household technologies (buyind) increases with education, number of children under 12 years of age, and number of adults 19 to 65 years of age. The relationship between children under 12 and the adoption of energy efficient technologies may occur because children increase households concerns about the future environment. Alternatively, the result may occur because children under 12 years of age tend to live in households with young to middle-age heads, who in turn have a higher propensity to purchase energy efficient technologies. The statistically negative parameter estimate for the number of household members over 65 years of age provides support for the later explanation. Considerable variation in country specific effects is also found, compared to the country benchmark of Germany, even after controlling for household characteristics. Belgium, Denmark, France, and Norway are estimated to have higher household propensities to adopt energy efficient technologies than Germany, while Bulgaria, Greece, Hungary, and Romania are estimated to have lower propensities.

The more narrow measure of household adoption of energy efficient technologies, the share of household bulbs which are CFLs, generally shows a weaker association with household characteristics than for the broader multi-technology index. Education is still positively associated with adoption, but the only household composition variable that remains significant is the positive association with number of children less than 12 years of age. Similarly, Denmark, France, and Norway no long show higher propensities to adopt energy efficient technologies (in this case CFL bulbs) than German households.

Household characteristics also show a similar relationship with the index of household knowledge. Education, number of children under 12 years of age, and number of adults 19 to 65 years of age are positively associated with the knowledge index, while the number of household members over 65 years of age is negatively associated with the index. Again, the higher level of knowledge may stem directly from age (with young to middle aged households being most likely to have children under 12), or the presence of children household may increase concerns for the future environment. In terms of country effects, the knowledge base in Germany appears to be high with only Denmark having a statistically higher knowledge index after controlling for household characteristics. On the other hand, households in Belgium, Bulgaria, The Czech Republic, Hungary, Norway, and Romania have lower knowledge indexes than in German.

Somewhat surprisingly, regression results for the index for use of energy conservation practices in the home look rather different from those for the technology adoption and knowledge indexes. The conservation practice index increases with education, number of children less than 12 years of age, and adults 19 to 65 years of age, and decreases with adults over 65 years of age in the household. However, all sample countries have a higher index than Germany after controlling for these characteristics.[4] The results suggest that in a cross-country perspective a high level of knowledge of energy use and available energy-saving technologies in a country does not imply the country will also show high propensities for energy conservation behavior. This result could potentially

[4] German households in the dataset report relatively low levels of use of energy-saving ‘sleep’ modes on computer monitors and desktops, as well as a low propensity to ‘always’ turn the lights off when leaving a room. These variables are given the greatest weight in generating the efficiency index via factor analysis.

arise from the ‘rebound effect’, where households respond to increased energy efficiency with increased energy usage or decreased conservation and, thereby, offset some of the technology induced gains.

In terms of attitudes, the propensity to state electricity savings is the most important reason for greenhouse gas reductions increases with education. However, the propensity decreases with the number of children 12 to 18 years of age and number of adults over 65 years of age. Again, the result implies that stated environmental concerns are more prevalent among young to middle age households. Stated importance of electricity savings for green house gas reductions also appears to be lower in Eastern European countries, with Bulgaria, Hungary, and Romania expressing lower importance compared to Germany. On the other hand, the stated importance of electricity savings for greenhouse gas reductions tends to be higher in The Czech Republic, Denmark, France, Greece, and Portugal than in Germany.

The results look very different when estimating associations with the stated importance of electricity reductions for financial savings. The probability of stating financial savings as the most important reason decreases with education, possibly reflecting the higher emphasis put on cost savings in low education – low income households. On the other hand, the stated importance of financial savings increases with the number of family members over 65 years of age. This result may again reflect lower income levels in elderly households or may stem from greater frugality with age. In terms of country effects, Germans appear to put the greatest importance on electricity savings for financial reasons, with Belgium, Denmark, France, Greece, Hungary, Norway, and Portugal all showing lower propensities to state financial savings as the most important reason to conserve electricity.

The last sets of regressions presented in table 3 specify the energy efficient technology adoption indexes and the energy conservation indexes as functions of each other, as well as other dependent variable measures of household knowledge and preferences. Household characteristics and country effects are also retained in these specifications. For the energy efficient technology adoption index regression, the impacts of household characteristics remain largely unchanged from the regression that excludes the other indexes in table 2. Although, the negative parameter estimate for the number of adults in the household over 65 years of age is no longer statistically significant at conventional levels in this specification. Country specific effects are also slightly muted, with households in France and Norway no longer having statistically different propensities to adopt energy efficient technologies compared to households in Germany. Interestingly, the knowledge index is not correlated with technology adoption. This result suggests that the provision of knowledge on energy use and energy saving technology options is likely to have only a limited impact on residential energy-efficient technology adoption. By contrast, the index for use of energy conserving practices in the home shows a very strong positive association with the adoption of energy efficient technologies. The parameter estimates for both attitude indexes are also positive, suggesting that adoption of energy efficient technologies are motivated by both strong environmental and strong financial concerns.

Regression parameter estimates for the technology index measured as share of household bulbs that are CFLs are also similar to those from the regression that excludes other indexes for household characteristics. However, country effects are more muted, with parameter estimates for Belgium, Greece, and Portugal no longer significant. The indicator for importance of electricity savings for financial reasons is also not significant when CFL share is used as the measure of technology adoption, suggesting financial concerns may have had a limited role in the diffusion of CFL bulbs despite the fact that engineering data suggests that potential cost savings are significant.

For the energy conservation practice index, education continues to have a positive impact, while the number of adults in the household has a negative impact. The strong propensity for German households to show a lower index of energy conservation practices compared to households in other countries also remains. Unlike for technology adoption, the knowledge index has a positive impact on the household energy conservation index (albeit significant at the $p=0.10$ level). Not surprisingly, the energy efficient technology adoption index is positively related to the household energy conservation index. This result suggests the 'rebound effect' may not be strong. The indicators for stated importance for greenhouse gas reductions and financial savings in electricity conservation also continue to have positive coefficients.

6. Discussion and Conclusions

The regression models employed in this analysis are reduced form in nature and appropriate caution should be employed in attributing causality rather than correlation to parameter estimates. However, several findings have important implications for the design of residential energy policies in Europe. First, knowledge of household energy consumption and energy-efficient technology options is weakly associated with household energy conservation practices, but is not associated with household adoption of energy-efficient technologies. Thus, information campaigns focused strictly on the energy saving characteristics of improved technologies may have a limited impact on diffusion.

On the other hand, strong environmental and financial concerns of households for energy savings can both be used to motivate technology adoption. But the results suggest that environmental and financial concerns are associated with different education – income groups. Low education (and presumably low income) households are primarily motivated by financial savings to save electricity. Household energy conservation and energy-efficient technology adoption campaigns targeted at households with low education and low income levels should, therefore, highlight the financial savings associated with the adoption of improved conservation practices and technologies. Financial subsidies may also provide disproportionally strong incentives for these households. Higher education – income groups are more motivated to save energy by environmental concerns. Thus, conservation and technology adoption programs targeted to higher education – income groups should focus on highlighting the positive environmental spillovers associated with reduced energy consumption.

As expected, young and middle-aged household cohorts are more amenable to energy-efficient technology adoption and energy conservation practices than households composed primarily of older adults. Motivations also appear to differ with the age structure of households, with households with younger children placing greater importance on energy savings for environmental reasons and households with a greater share of elderly placing greater importance on financial savings. Again, this suggests different mechanisms may need to be developed to promote household energy-efficient technology adoption and energy conservation across age-cohorts.

Finally, the results highlight the fact that despite a broadly compatible framework of energy policies across EU countries, significant cross-country variation remains in propensities to adopt energy-efficient technologies and implement energy conserving practices in the home. Households in Eastern European countries generally show lower levels of household energy-efficient technology adoption when compared to Germany and other Western European countries, this may stem in part from later implementation of energy labeling frameworks. Households in Eastern European countries also place less importance on electricity savings for environmental reasons. East – West differences in the use of energy conservation practices appear to be less pronounced, although conservation may again stem from different motivations in the regions. Overall the results suggest that effective EU policies to promote residential energy-efficient technology adoption and energy conservation must be sensitive to country differences. A major challenge will, therefore, be to generate a set of uniform EU energy policies that remain flexible enough to address country specific constraints.

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Table 1: Descriptive Statistics

Variable	Description	Mean	St. Dev.
Dependent			
buyind	Energy-efficient technology adoption index	0.000	0.950018
cflshare	Share of bulbs that are CFLs	0.166	
knowledge	Knowledge of energy use and conservation measures index	0.000	0.284257
effindex	Use of energy conserving practices index	0.000	0.80055
goalghe	Energy savings is most important for greenhouse gas reductions=1	0.196	
goalsav	Energy savings is most important for financial reasons=1	0.632	
Independent			
education	0=less than high school, 1=high school, 2=trade or vocational, 3=university	2.152	0.988381
lt12	Number of household members less than 12 years of age	0.360	0.726682
to18	Number of household members 12 to 18 years of age	0.222	0.532931
to65	Number of household members 19 to 65 years of age	1.981	1.010384
gt65	Number of household members greater than 65 years of age	0.209	0.534867
belgium	Resident of country=1	0.109	
bulgaria		0.104	
czech		0.098	
denmark		0.085	
france		0.020	
germany		0.111	
greece		0.085	
hungry		0.100	
norway		0.052	
portugal		0.109	
romania		0.127	
Number of observations:		4,896	

Table 2: Regression of indexes on household characteristics and countries

	OLS Estimates buyind		Tobit Estimates cflshare		OLS Estimates knowledge		OLS Estimates effindex		Probit Estimates goalghe		Probit Estimates goalsav	
	Parameter Est.	Stand. Err.	Parameter Est.	Stand. Err.	Parameter Est.	Stand. Err.	Parameter Est.	Stand. Err.	Parameter Est.	Stand. Err.	Parameter Est.	Stand. Err.
education	0.070 **	0.013	0.030 **	0.006	0.018 **	0.004	0.128 **	0.011	0.075 **	0.023	-0.110 **	0.021
lt12	0.142 **	0.017	0.020 **	0.008	0.008 *	0.005	0.024 *	0.015	0.011	0.030	0.019	0.027
to18	0.028	0.023	0.009	0.010	-0.008	0.007	-0.013	0.020	-0.099 **	0.042	-0.009	0.036
to65	0.076 **	0.014	0.005	0.006	0.008 **	0.004	0.027 **	0.012	-0.025	0.025	0.001	0.022
gt65	-0.060 **	0.026	-0.004	0.012	-0.017 **	0.007	-0.117 **	0.022	-0.141 **	0.051	0.079 *	0.042
belgium	0.180 **	0.053	0.039 *	0.023	-0.062 **	0.015	0.350 **	0.046	-0.031	0.097	-0.965 *	0.083
bulgaria	-0.439 **	0.054	-0.184 **	0.026	-0.184 **	0.016	0.366 **	0.047	-0.329 **	0.106	0.031	0.087
czech	0.079	0.055	0.148 **	0.024	-0.232 **	0.016	0.656 **	0.048	0.170 *	0.097	-0.012	0.088
denmark	1.111 **	0.056	0.044	0.024	0.327 **	0.016	0.736 **	0.048	0.892 **	0.092	-0.149 *	0.088
france	0.221 **	0.092	0.021	0.041	-0.034	0.026	0.679 **	0.080	0.773 **	0.144	-0.471 **	0.140
greece	-0.380 **	0.056	0.017	0.025	0.013	0.016	0.777 **	0.049	0.863 **	0.093	-1.479 **	0.094
hungry	-0.308 **	0.053	0.067 **	0.023	-0.219 **	0.015	0.076 *	0.046	-0.552 **	0.115	0.325 **	0.091
norway	0.175 **	0.065	-0.012	0.029	-0.073 **	0.019	0.469 **	0.057	-0.039	0.119	-0.311 **	0.101
portugal	0.083	0.053	0.009	0.024	-0.022	0.015	0.573 **	0.046	0.342 **	0.092	-0.398 **	0.083
romania	-0.300 **	0.051	-0.216 **	0.024	-0.191 **	0.015	0.267 **	0.044	-0.489 **	0.105	0.089	0.083
constant	-0.344 **	0.050	-0.025	0.023	0.021	0.014	-0.721 **	0.043	-1.083 **	0.091	0.840 **	0.081
Adj. R2	0.214				0.284		0.159					
Log-likelihood			-2491.7						-2149.5		-2842.4	

Table 3: Relationships between indexes, household characteristics, and countries

	OLS Estimates buyind			Tobit Estimates cflshare			OLS Estimates effindex		
	Parameter Est.		Stand. Err.	Parameter Est.		Stand. Err.	Parameter Est.		Stand. Err.
education	0.048	**	0.013	0.023	**	0.006	0.117	**	0.011
lt12	0.137	**	0.017	0.019	**	0.008	0.004		0.015
to18	0.033		0.023	0.012		0.010	-0.012		0.020
to65	0.072	**	0.014	0.004		0.006	0.017		0.012
gt65	-0.038		0.025	0.005		0.012	-0.105	**	0.022
belgium	0.144	**	0.054	0.021		0.024	0.373	**	0.046
bulgaria	-0.493	**	0.055	-0.198	**	0.026	0.449	**	0.048
czech	-0.035		0.056	0.112	**	0.025	0.657	**	0.048
denmark	0.951	**	0.059	-0.015		0.026	0.513	**	0.052
france	0.093		0.092	-0.030		0.041	0.627	**	0.079
greece	-0.506	**	0.059	-0.037		0.026	0.832	**	0.050
hungry	-0.314	**	0.053	0.069	**	0.024	0.142	**	0.046
norway	0.103		0.065	-0.035		0.029	0.465	**	0.056
portugal	-0.017		0.053	-0.027		0.024	0.564	**	0.045
romania	-0.337	**	0.051	-0.224	**	0.025	0.336	**	0.044
knowledge	0.025		0.050	0.004		0.022	0.083	*	0.043
effindex	0.176	**	0.016	0.051	**	0.007			
buyind							0.132	**	0.012
goalghe	0.085	**	0.033	0.070	**	0.015	0.183	**	0.029
goalsav	0.065	**	0.028	0.010		0.013	0.110	**	0.024
constant	-0.282	**	0.057	-0.005		0.026	-0.789	**	0.048
Adj. R2	0.234						0.188		
Log-likelihood				-2453.8					

Table A.1: Year of Country Implementation of EU Energy Consumption Labeling Directives

	Refrigerators and Freezers	Washing Machines	Dishwashters
Belgium	1999	1999	1999
Bulgaria	2006	2006	2006
Czech Republic	2004	2004	2004
Denmark	1995	1996	1999
France	1995	1996	1998
Germany	1998	1998	1998
Greece	1996	1997	1997
Hungry	2002	2002	2002
Norway	1996	1996	1996
Portugal	1995	1996	2000
Romania	2001	2001	2001

Source: MURE2 database