Ca' Foscari University of Venice

Department of Economics

Working Paper

Enrica De Cian
Filippo Pavanello
Teresa Randazzo
Malcolm Mistry
Marinella Davide

Does climate influence households' thermal comfort decisions?

ISSN: 1827-3580
No. 02/WP/2019

Working Papers
Department of Economics
Ca' Foscari University of Venice
No. 02/WP/2019
ISSN 1827-3580

Does climate influence households' thermal comfort decisions?

Enrica De Cian
Ca' Foscari University of Venice and CMCC

Filippo Pavanello
Ca' Foscari University of Venice

Teresa Randazzo
Ca' Foscari University of Venice

Malcolm Mistry
Ca' Foscari University of Venice and CMCC

Marinella Davide
Ca' Foscari University of Venice and CMCC

Abstract
This paper investigates how households have been adapting to climate change through the use of two technologies important for thermal comfort, air conditioning and thermal insulation. Merging a global gridded dataset of historical temperatures with the 2011 OECD EPIC survey, we study the determinants of installing air conditioning or adopting thermal insulation in response to a warmer climate in eight countries. After controlling for a set of demographic, socio-economic and attitudinal variables, we apply a binary probit model and find that exposure to a warmer climate influences only air conditioning adoption whereas, climatic conditions seem not to affect thermal insulation decisions which, instead, mainly depends on household wealth, dwelling characteristics, age, household size and propensity to energy-saving behaviours. This study does not find any evidence of a possible joint decision for the two technologies.

Keywords
Cross-section, climate change, adaptation, energy

JEL Codes
D12, O13, Q4

Address for correspondence:
Enrica De Cian
Department of Economics
Ca' Foscari University of Venice
Cannaregio 873, Fondamenta S.Giobbe
30121 Venezia - Italy
e-mail: enrica.decian@unive.it

The Working Paper Series
is available only on line
(http://www.unive.it/pag/16882/)
For editorial correspondence, please contact:
wp.dse@unive.it

Department of Economics
Ca' Foscari University of Venice
Cannaregio 873, Fondamenta San Giobbe
30121 Venice Italy
Fax: ++39 041 2349210

Does climate influence households' thermal comfort decisions?

Enrica De Cian, Ca' Foscari University of Venice and CMCC

Filippo Pavanello, Ca' Foscari University of Venice

Teresa Randazzo, Ca' Foscari University of Venice

Malcolm Mistry, Ca' Foscari University of Venice and CMCC

Marinella Davide, Ca' Foscari University of Venice and CMCC

Abstract

This paper investigates how households have been adapting to climate change through the use of two technologies important for thermal comfort, air conditioning and thermal insulation. Merging a global gridded dataset of historical temperatures with the 2011 OECD EPIC survey, we study the determinants of installing air conditioning or adopting thermal insulation in response to a warmer climate in eight countries. After controlling for a set of demographic, socio-economic and attitudinal variables, we apply a binary probit model and find that exposure to a warmer climate influences only air conditioning adoption whereas, climatic conditions seem not to affect thermal insulation decisions which, instead, mainly depends on household wealth, dwelling characteristics, age, household size and propensity to energy-saving behaviours. This study does not find any evidence of a possible joint decision for the two technologies.

JEL Codes: D12, O13, Q4
Keywords: Cross-section, climate change, adaptation, energy.

Acknowledgement

This paper has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme under grant agreement No 756194 (ENERGYA).

1 Introduction

Global average temperature has increased by almost 1 °C already since the pre-industrial revolution. While mitigation is needed in order to limit future warming and to manage the risks of climate change, adaptation strategies are also required to cope with the climate that has already changed. Targeted policies also based on future adaptation responses, such as improving the energy efficiency of buildings and appliances, might reduce both the impacts and the mitigation costs of changes in climate conditions. To maintain their thermal comfort, households can adapt to higher temperatures by increasing their demand for residential buildings' cooling during the summer as well as by reducing space heating in winter. Space cooling is indeed the fastest growing energy service in buildings (IEA, 2018[29]), bearing the risk of creating a maladaptive response (Hallegatte et al., 2007[27]). A reactive adaptation strategy, like air conditioning (AC), is indeed easier and cheaper to adopt, but not necessarily sustainable over the long-term. Rapid diffusion and use of this energy-intensive technology could create trade-offs with other sustainable development goals and with the attempt of reducing greenhouse gas emissions (GHGs). The steady increasing diffusion of air conditioning is one of the most critical blind spots in today's energy debate (IEA, 2018[29]), often overlooked in low carbon scenarios. A proactive adaption strategy, like improving thermal insulation (TI), is likely to be more effective in the long-run. Thermal insulation is an energy-efficient investment, which is used for both heating and cooling dwelling spaces, contributing to reduce energy-use, generating money savings and cutting GHG emissions.

In this paper, we aim to study how households adapt to a warmer climate by adopting two energy-using durable goods that provide thermal comfort services. We analyse the determinants of the decision of adopting air conditioning or thermal insulation in the primary residence in response to a warmer climate, while controlling for a set of demographic, socio-economic and attitudinal variables that might also influence adoption decisions. We are also interested to study whether households might combine the adoption of the two technologies. As measure of the typical intensity and duration of hot and cold climate we use long-term average cooling degree days (CDDs) and heating degree days (HDDs) over the period 1986-2011.

Our contribution to the literature is threefold. First, there are still few studies (e.g. Davis and Gertler, 2015[16]; Gillingham et al., 2012[25]) on the determinants of the choice of adopting these thermal comfort technologies (extensive margin). Most previous papers on air conditioning adoption, such as Sailor and Pavlova (2003)[48] and McNeil and Letschert (2008)[42], focus on predicting how households will adapt, in terms of air conditioning

ownership, to changes in climate conditions. However, their analysis does not capture which factors determine a greater diffusion of residential air conditioning, beside income and CDDs, and how the influence of those factors might vary across countries and income levels. The scarce literature on thermal insulation adoption, instead, focus on extensive margin responses to dwelling characteristics and other socio-economic variables (Gillingham et al., 2012[25]; Kriström and Krishnamurthy, 2014[37]; Ameli and Brandt, 2015[4]). To our knowledge, there are no contributions investigating whether thermal insulation adoption responds to changes in climate. Moreover, we enrich the empirical studies on the new climate-economy literature using as propagation channel the energy end-use consumption for air conditioning and thermal insulation. Most existing contributions (e.g. Deschênes and Greenstone, 2007[21]; De Cian et al., 2007[17]; Auffhammer and Aroonruengsawat, 2011[9]; De Cian and Sue Wing, 2017[18]), look at weather shocks. In this work we examine long-run households' adaptation using cross-sectional variation. Finally, we contribute to increase the empirical evidence on cooling and thermal insulation demand in Europe. New contributions are necessary to improve European Union energy policy. Our analysis indeed involves six European countries (France, Netherlands, Spain, Sweden, Switzerland).
The rest of the paper develops as follows. Section 2 describes the data used for the econometric analysis. Section 3 outlines the methodological approach. Section 4 presents the empirical results of the econometric analysis, along with their interpretation and discussion. Section 5 concludes highlighting policy implications.

2 Data

In order to investigate whether different climatic conditions contribute to influence cooling and thermal insulation demand, after controlling for a set of socio-economic, demographic, and attitudinal household-level variables, we combine a household survey data with a rich set of information related to energy behaviours in selected OECD countries with high-resolution, historical climate data.

2.1 The 2011 OECD EPIC survey

The 2011 Environmental Policy and Individual Behaviour Change (EPIC)[1] survey has been conducted by the Organisation for Economic Co-operation and Development (OECD). The recipients of this survey are households from

[1]For more details, we recommend OECD (2014)[45]

eleven countries (Australia, Canada, Chile, France, Israel, Japan, Korea, Netherlands, Spain, Sweden and Switzerland), collecting 12202 participants[2]. The survey was constructed through both stratification and quota sampling methods in order to ensure that each country-sample was representative of the related nation. For each country-sample, OECD sets country-specific quota targets based on statistics provided by national agencies. Stratification and quota targets were imposed for four variables, namely gender, age, region and income[3].

The dataset has been published a few years ago, and numerous studies have been published. Yet, previous works based on the 2011 OECD EPIC survey (e.g. Kriström and Krishnamurthy, 2014[37]; Ameli and Brandt, 2015[4]; Dato, 2017[15]) focus on the role of renewable energy and energy-efficient technologies, without taking into account the role of climate variables in their analyses. The availability of geocoded households has been exploited by only one paper, Brown et al. (2014) [12], which look at how spatial clustering of attitudinal characteristics mediate the effect of environmental policies. To our knowledge, our study is the first to add the role of climate to the rich set of variables described in the dataset (see Section 2.4).

2.2 Combining the survey with climate data

To study the impact of different climatic conditions on thermal comfort's decisions we use long-term averages of annual cooling (CDDs) and heating (HDDs) degree days, measures of the typical intensity and duration of hot and cold climate, which are commonly used as coavariates in the energy demand literature (e.g. Isaac and Van Vuuren, 2009[34]; Deschênes and Greenstone, 2011[22]; Rapson, 2014[46]).

HDDs and CDDs have been calculated using the daily temperature (degree C) data computed from the 3-hourly global surface gridded temperature

[2]Two EPIC surveys have been conducted, one in 2008 and one in 2011. We use only the 2011 OECD EPIC survey because households are geocoded, which is the key feature that makes it possible to merge it with climate data.

[3]For gender the aim was about half male and half female for all the surveyed countries. Age was stratified, identifying five age groups: 18 to 24, 25 to 34, 35 to 44, 45 to 54 and 55 to 69. Regions were stratified as well. However, quotas were built for macro-regions, which include three to five regions (for instance, 11.0% of French households has to come from the Sud-Ouest. This macro-region includes the following regions Aquitaine, Limousin, Midi-Pyrénées and Poitou-Charentes). Stratification of income was obtained for each country estimating households' after-tax income quintile. Then, filling the survey, each household chose its income category. Households kept filling the survey until the quotas were reached. When a quota was reached, a household, which had that characteristic, was stopped completing the questionnaire (see Annex B in OECD, 2014[45]).

(0.25° x 0.25° resolution, approximately 27-28 km) fields obtained from the Global Land Data Assimilation System (GLDAS), Rodell et al. (2004)[47], for the years 1986-2011. For each grid-cell the CDD/HDD are calculated using the general method and fixing 18.3 °C as temperature baseline[4] as follows :

$$CDD = \sum_{d=1}^{N_d} (\gamma_d)(T - T_b)$$

$$HDD = \sum_{d=1}^{N_d} (1 - \gamma_d)(T_b - T)$$

where N_d is the number of days in a specific month or year; T is the mean daily temperature; γ_d is the binary multiplier (if $T > T_b$ then $\gamma_d = 1$, 0 otherwise); T_b is the temperature threshold (18.3 °C).

Since the EPIC survey has been conducted in 2011, the explanatory variable to be used in the regression analysis is the long-term average of HDDs and CDDs over the period 1986-2011. This is in line with the practice of defining climatic conditions as the averages over a sufficiently long period of time (usually about 30 years, see Glossary in IPCC, 2014[33]). We use the latitude and longitude information provided in the EPIC survey to merge households with the resulting HDDs and CDDs. All non-geocoded households are dropped, moving from 12202 to 7449 observations. This means we drop 3 out of 11 countries available in the dataset, namely Chile, South Korea and Israel. As the 2011 OECD EPIC survey was built using the quota sampling method, we check the post-merging quota targets for the full-sample and for the country-samples in order to confirm sample representativity.

Figure 1 displays CDDs and HDDs maps for the eight EPIC countries included in the analysis. Each black point represents a geocoded household. In more temperate countries, like France, Japan, Netherlands and Spain, households are quite uniformly distributed throughout the area. Instead, in countries where hot or cold climate is dominant, most participants results to live in temperate regions.

2.3 The wealth index

The literature shows that income is a key driver of thermal comfort technology adoption (e.g. Ameli and Brandt, 2015[4]; Kriström and Krishnamurthy,

[4]18.3 °C is the most used temperature threshold in the literature (e.g. Sailor and Pavlova, 2003[48]; Aebischer et al., 2007[1]; Akpinar-Ferrand and Singh, 2010[5]; Deschênes and Greenstone, 2011[22]; Rapson, 2014[46]; Cohen et al., 2017[14]). We stick to this thresholds being our countries located in temperate regions.

2014[37]; Krishnamurthy and Kriström, 2015[36]; Dato, 2017[15]). Yet, in the context of a cross-sectional analysis, self-reported income might be prone to several issues. Annual income is subject to short-run shocks (e.g. a household head might lose its job during the year), and therefore likely to be measured with error. Moreover, in general, households are reluctant to declare their income and in fact, only 5666 households report this information. A way to overcome the large number of missing information for the income variable is to build a wealth index following Filmer and Pritchett (2001)[24]. The wealth index measures the-socio economic status (SES) of each household.
Compared to income, the wealth index is a more stable variable better capturing the long-term situation of a household since it is an asset-based index. The number of assets normally used to build the index range from 10 to 30 (Vyas and Kumaranayake, 2006[51]). We use 17 variables in a binary or continuous form. Table A.1 displays for each asset its factor score or weight. A household which owns a car and big detached house furnished with more electric appliances would reach a higher SES. The correlation between the wealth index and income is almost 0.7. The wealth index we obtain results to be a good proxy of the income variable.

2.4 Variable description and summary statistics

Table 1 describes the variables of interest, as well as their nature. Our explanatory variables can be grouped into four main groups. The climate variables include the measures of the typical intensity and duration of hot and cold climate, namely HDDs and CDDs. The socio-economic characteristics are variables defining the socioeconomic situation of a household, including occupation, SES, income and dwelling characteristics. Demographics contain all those factors that identify a household's structure, such as household head's sex and age. Finally, attitudinal characteristics are variables which summarise the pro-environmental and energy-saving attitude of a household. Table 2 reports the means and standard deviation (in parenthesis) for each variable (excluding occupation) in each country-sample and in the total sample. The descriptive statistics suggest that 36.7% of EPIC OECD participants have adopted air conditioning. The countries where there is the highest diffusion of air conditioning are Japan, Australia, Spain and Canada, counting respectively 89.9%, 72.6%, 51.8% and 48.5% of their country-sample with at least an air conditioner. Sweden, France, Netherlands and Switzerland are those with the lowest diffusion, respectively 15.8%, 13.7%, 13.6% and 7.5%. These results for air conditioning adoption seem to be clearly related to the cooling degree days distribution in the eight countries. Most countries with the highest AC diffusion are also the ones with the highest long-term (1986-

2011) average cooling degree days. Japan, Spain and Australia indeed report average cooling degree days equal to, respectively, 703, 590 and 569. The reverse is true as well, namely most less exposed to hot climate countries present a lower adoption of air conditioning.

For thermal insulation, 43.1% of the EPIC sample has implemented this energy-saving technology. Australia and Netherlands, with respectively 55.1% and 56.1%, lead in terms of thermal insulation adoption. The only country whose adoption rate results pretty lower than the average is Japan, with 26%. Contrary to air conditioning adoption, in Table 2 there is no evidence of a clear correlation between thermal insulation and the climate variables.
The second climate variable, heating degree days, presents an average of 2726. As expected, the countries which report the highest average exposures to cold climate are Canada (4431), Sweden (4197) and Switzerland (3345). Australia (1072) and Spain (1601) are, instead, significantly the less exposed to cold climate.
Average household yearly income is reported equal to 41734€. Three countries significantly differ from the total sample average. The Spanish average income is the lowest, 29316€. Japan and Switzerland indicate the highest averages for income, respectively of 52210€ and 62139€. While this could be not surprising for Japan, since Japanese households are the most-educated (4.9 years of post-secondary school education), Swiss households are, instead, the third less educated (2.9). The highest means for the asset-based index are, instead, reported in Canada (0.25) and in Netherlands (0.26). The full sample average length of households post-secondary school education is 3.4 years. This suggests that most heads of household have not university-level degree.
Table 2 also reports means of variables related to both where households live and their residences. Most households live in urban area (59.3%), including both urban and suburban zones. The highest percentages are reached by Australian (80.6%) and Canadian (72.6%) participants. In Switzerland households generally have their primary residence in rural areas (38.7%). Observing the rates about primary residence type, most households live in a detached house rather than in an apartment (37.8%). Only in Spain (73.8%), Sweden (53.8%) and Switzerland (64.2%) the number of people living in an apartment exceeds that one for living in a detached house. Data also report that the average house size is 116.772 m^2. At country-sample level, the average size of primary residences in Australia is significantly larger (about 154 m^2). The smallest ones are in Sweden (about 98 m^2) and France (almost 100 m^2). More than 60% of total households owns primary residence. Switzerland is the only country which reports tenants as the majority (37.4%

of ownership rate). In our sample, respondents on an average live in their primary residence for about 13 years, with only Japanese participants living noticeably longer in their primary residence, almost 19 years.
Focusing on demographics, data report the average household age equal to about 43 years. The oldest countries are Netherlands (45) and Japan (44). The average household size results equal to about 2.7 people. In all countries there are on average at least two people in each household. Only in both Spain and Japan the average family size exceeds 3 people. However, it is not surprisingly that the lowest average share of minors in the family is reported for Japan (12.2%). For the full sample the average share of minors in the households is, instead, about 14.7%. The highest average shares are attained by France (16.3%) and Sweden (16.1%). Table 2 also suggests that the average distribution of male and female in the sample is almost equal. Male average rate (50.2%) is slightly over female one (49.8%).
The attitudinal characteristics group includes the variable environmental attitude index. Answering to some targeted questions in the EPIC survey, households have declared, for instance, whether they consider the environmental impacts being overrated or whether they are willing to change their lifestyle for the environmental sake or whether they believe in technological progress to deal with environmental issues. With an interval between -2 and 2 this index summarises household's attitude with respect to environment. Some previous studies use this index to divide their sample in three groups, namely sceptics, altruists and technological optimists (e.g. Ameli and Brandt, 2015[4]; Brown, 2014[12]). The average environmental attitude score is 0.430. The index is reported positive in all country-samples. Data suggest that while Sweden has the highest attitudinal score (0.621), Japan has the lowest one (0.109). Another index which we take into account is the environmental concern index. This index summarises household's concern for specific environmental issues (climate change, water pollution, waste generation, loss of biodiversity, air pollution and natural resource depletion), providing a score between 0 and 10 such that the higher the score, the higher the concern is. In the sample the average environmental concern score is around 7. While the most concerned households live in Spain, the less concerned ones are from Netherlands. The last index we include in the analysis is the energy behaviour index, which summarises the energy-saving behaviours of a household in a score between 0 and 10. The higher the score is, the more frequent the household implements behaviours such as switching off the lights or cutting down heating or air conditioning to save energy consumption. The average index value for our sample is equal to 7. Spain has the highest score, followed by France and Australia. Instead, the lowest scores is reported in Sweden. Finally, Table 2 captures average values of the membership in an

environmental NGO. The average commitment is around 10%, with Switzerland and Japan reporting respectively the highest (22.8%) and the lowest (2.3%) rates.

3 Empirical model

The empirical framework is based on a discrete choice model of thermal comfort investment decisions for air conditioning and thermal insulation. Following McFadden (1973[39], 1981[40], 1984[41]), we apply basic utility theory to the problem of choosing whether to invest in thermal comfort or not. Specifically, we model households' choices to adopt air conditioning and thermal insulation. Thus, for any household i a random utility model (RUM) is applied as follows:

$$\max_{c_i, \mathbf{tc_i}} U_i = U(c_i, \mathbf{tc}_i) \quad (1)$$

$$\text{s.t. } c_i + \mathbf{P}'\mathbf{tc}_i = y_i$$

where U_i is the utility function, c_i is the expenditure in consumption goods, $\mathbf{P}$ is the vector of prices of thermal comfort whereas the price of other goods c is normalized to 1, $\mathbf{tc}_i$ is a vector which represents investment in thermal comfort and y_i is the income.

The vector $\mathbf{tc}_i$ can be defined as:

$$\mathbf{tc}_i = \begin{pmatrix} ac_i \\ ins_i \end{pmatrix} \quad (2)$$

Therefore, in order to invest in thermal comfort, household i may choose whether to install air conditioning, ac_i, or thermal insulation, ins_i.
For any household i we can assume that:

$$U_i^c = \frac{\partial U_i}{\partial c_i} > 0$$

$$U_i^c = \frac{\partial U_i}{\partial \mathbf{tc}_i} \geq 0$$

- the marginal utility with respect to consumption is strictly positive;
- the marginal utility with respect to investment in thermal comfort is weakly positive. This allows the possibility for an household to decide not to invest in thermal comfort.

Given the above maximisation problem, in this framework the dependent variable is modeled as a latent variable:

$$tc^*_{ij} = \mathbf{x}'_{ij}\beta + \epsilon_{ij} \tag{3}$$

where tc^*_{ij} is the latent dependent variable which reflects the preferences of household i in terms of thermal comfort, namely the net marginal benefit derived from investments in air conditioning, $j = ac_i$, or thermal insulation, $j = ins_i$. $\mathbf{x}_{ij}$ is a vector of regressors for each thermal comfort technology and includes attribute variables and characteristic variables. The formers describe the choice (e.g. climate variables, CDDs and HDDs). The latters describe the decision maker, namely the household, and include socio-economic variables (e.g. wealth index/income, occupation, housing characteristics), demographic variables (e.g. sex, age, education, share of under 18) and attitudinal variables (e.g. membership in an environmental organisation and policy indexes). The vector of coefficients which are estimated is labeled as β. Finally, ϵ_{ij} is the random, independent error term that takes account of all unobserved/omitted variables affecting household i's preferences.
Since tc^*_{ij} is a latent variable, we study households' decision of investing in one of the two thermal comfort technologies, tc_{ij}. It is a dichotomous variable determined by the following decision rule:

$$tc_{ij} = \begin{cases} 1 & \text{if } tc^*_{ij} > 0 \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

This means that when the net benefit derived from investment in a thermal comfort technology j is positive, household i decides to invest in j, namely $tc_{ij} = 1$. Otherwise, when the net marginal benefit derived from investment in a thermal comfort technology j is negative, household i does not spend for j, namely $tc_{ij} = 0$. To fit the above model, we use a probit model declined as follows:

$$P(tc_{ij} = 1|\mathbf{x}_{ij}) = \int_{-\infty}^{\mathbf{x}'_{ij}\beta} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{z^2}{2}} dz \tag{5}$$

For N observations in the dataset, the parameter vector β is computed through the maximum likelihood estimation, for which the probit log-likelihood function for thermal comfort technology j is the following:

$$\ln L_j = \sum_{i=1}^{N} [tc_{ij} \ln \Phi(\mathbf{x}'_{ij}\beta) + (1 - tc_{ij})(1 - \Phi(\mathbf{x}'_{ij}\beta))] \tag{6}$$

The marginal effects are evaluated at their means and calculated according to this relation (Greene, 2003[26]):

$$\frac{\partial P(tc_{ij} = 1|\mathbf{x}_{ij})}{\partial x_{ijk}} = \phi(\mathbf{x}'_{ij}\beta)\beta_k \tag{7}$$

where k is the index indicating one of the K explanatory variables included in the vector $\mathbf{x}_{ij}$ and $\phi()$ is the probability density function of the standardised normal distribution. The predicted marginal effects estimate the probability of observing an household invests in a thermal comfort technology (tc_{ij}) when the continuous variable changes infinitesimally. In the case of a dummy variable (e.g. home type, living in an urban area) the resulting marginal effect provides an estimate of the probability of observing an household invests in a thermal comfort technology (tc_{ij}) when the dummy variable d shifts from 0 to 1. The marginal effects are calculated as follows (Greene, 2003[26]):

$$P((tc_{ij} = 1|\mathbf{x}_{ij}), d = 1) - P((tc_{ij} = 1|\mathbf{x}_{ij}), d = 0) \tag{8}$$

Thus, they are equal to the difference between the estimated probability of investing in a thermal comfort technology j, namely $tc_{ij} = 1$, when $d = 1$ and when $d = 0$, evaluating all the other explanatory variables (dummies as well) at their means.

3.1 Research hypotheses

Our empirical analysis is guided by a set of hypotheses we have formulated building on two major branches of literature looking at the determinants of energy demand and of air conditioning.

Hypothesis 1: Exposure to a hot climate as measured by CDDs raises the probability for a household to purchase air conditioning. Exposure to both hot and cold climate, as measured by CDDs and HDDs, can influence the probability of improving houses thermal insulation.
Even though most contributions agree on the positive correlation between CDDs and air conditioning (e.g. Sailor and Pavlova, 2003[48]; Biddle, 2008[10]; McNeil and Letschert, 2008[42]; Rapson, 2014[46]), the evidence is mostly confined to the US. Moreover, there is almost no evidence on the possible nonlinearities in the relation between air conditioning and climate variables. Only Biddle (2008) finds a statistically consistent nonlinearity with the interaction of CDDs and HDDs. We examine the existence of possible nonlinearities by including the term (CDD^2) in order to capture the saturation

of air conditioning with CDD and the interaction term (CDDxHDD) to account for indoor acclimatisation effects. We expect the sign of the former to be negative indicating saturation when approaching 100%. Instead, the latter term is expected to be positive, suggesting that in colder countries an increase in CDDs has a larger impact on air conditioning adoption because people are less used to hot climate and therefore more sensitive.
Regarding the relationship between thermal insulation and climate, although the literature acknowledges the role of house characteristics, no formal in-depth analysis has been conducted in relation to climate variables. Only Gillingham et al. (2012)[25] find that thermal insulation is more likely to be present in colder areas. Therefore, we hypothetise that both CDDs and HDDs could positively affect the incentive to implement thermal improvements, though the latter driver could prevail especially in cold countries.
Figure 2 shows the correlations[5] between air conditioning adoption and the two climatic variables. As we expected, there is a strong positive correlation with cooling degree days. This suggest that hot climate might have a strong influence on the decision of installing air conditioning. The correlation between thermal insulation decision and the two climatic variables highlights two opposite effects. Exposure to a cold climate (HDDs) might increase the household's incentive to install thermal insulated walls/roof, in order to keep a warm indoor climate. On the other hand, a hot climate (CDDs) seems to reduce this incentive.

Hypothesis 2: A household with higher income and higher wealth is more likely to adopt air conditioning. Income and wealth index may positively influence the probability of installing thermal insulated walls/roof as well.
The existing literature has always used income as proxy for the socio-economic status of households. For the US, Rapson (2014)[46] highlights that higher income is associated with higher demand for cooling in electricity terms. Contributions on developing countries (e.g. McNeil and Letschert, 2008[42]; Akpinar-Ferrand and Singh, 2010[5]), to fit future AC market diffusion curves, model AC ownership rate as function of both cooling degree days and income. They suggest that growing incomes due to economic growth will raise AC market diffusion in developing countries. Davis and Gertler (2015)[16] also find that income is a significant determinant of the choice of adopting air conditioning. Regarding thermal insulation, there is evidence that the installation of such an energy conservation measure is related to income

[5]The correlation plots are built collapsing variables' data at their means by country and region. Each correlation plot presents the correlation with one observation (mean) for each region.

(e.g. Gillingham et al., 2012[25]; Ameli and Brandt, 2015[4]; Dato, 2017[15]). Figure 2 shows weak correlations between income and adoption of air conditioning or thermal insulation. The wealth index shows a strong and positive correlation with thermal insulation decisions.

Hypothesis 3: Living in an urban area raises the probability for a household to install air conditioning. The probability of adopting thermal insulation may be affected by the kind of area where household's residence is located as well, though there is no a priori whether this should be positive or negative. In the literature there is no evidence about this effect on air conditioning adoption. Previous works using the OECD 2011 EPIC survey suggest there is, instead, evidence that living in an urban area influences the investment choices in specific appliances, especially for renewable energy and energy conservation (see Ameli and Brandt, 2015[3]).
Figure 2, third row, shows the correlation between the two dependent variables and living in an urban area. The former shows a strong positive correlation with air conditioning adoption. This might be due to the heat island effect. The latter displays a negative correlation with thermal insulation. This might be due to the fact that, for instance, buildings in rural area could be more exposed to cold climate. Alternatively, since in our sample living in urban area is negatively correlated with being a home owner and positively correlated with living in apartments, households living in urban areas might be more likely to both live in apartments and be tenants. Hence, there might be more either constraints or less incentives to implement the technology in urban dwellings.

Hypothesis 4: Dwelling characteristics may affect the probability that a household decides installing at least an air conditioner. House characteristics may also influence the probability of improving energy conservation through thermal insulation.
We are interested in four dwelling characteristics, namely home size, home type, years of housing tenure and housing ownership. There is some evidence that home size (Rapson, 2014[46]), also proxied by the average number of rooms in a housing units (Biddle, 2008[10]), and when the house was built (Biddle, 2008[10]) are drivers of demand for cooling. The literature does not include evidence on the role of other home characteristics. Figure 2 shows that home tenure, home size and home ownership are positively related to air conditioning adoption. Instead, households living in an apartment seems to be less likely to adopt the space cooling technology.
Previous contributions (e.g. Gillingham et al., 2012[25]; Ameli and Brandt, 2015[4]; Dato, 2017[15]) suggest that there is a strong relationship between

home characteristics and the decision of investing in energy efficiency measure. Both Gillingham et al. (2012)[25] and Ameli and Brandt (2015)[4] highlight that thermal insulation is negatively related to home tenure and living in an apartment. This means that, first, this kind of energy conservation appliances are more likely installed in newly built or inhabited houses. Second, living in a multi-dwelling house rather in a detached house might make the choice of installation immobile appliances as thermal insulation difficult. Gillingham et al. (2012)[25] also find a positive relationship between thermal insulation adoption and home size. There is strong evidence that there exists a positive correlation with home ownership as well (Gillingham et al., 2012[25]; Kriström and Krishnamurthy, 2014[37]; Ameli and Brandt, 2015[4]). Owners have more incentives than tenants to invest in thermal insulation. Figure 2 is in line with the existing literature, suggesting a negative correlation with living in an apartment and a positive one with ownership. Correlation with housing tenure and home size is very low.

Hypothesis 5: Households' behaviour and attitude with respect to environment and energy can complicate the adoption of air conditioning. A pro-environmental and energy conservation-oriented household may also be more motivated to invest in thermal insulation.
While most contributions on the 2011 OECD EPIC survey include this set of variables, to a greater or lesser extent (e.g. Kriström and Krishnamurthy [37]; Krishnamurthy and Kriström, 2015[36]; Ameli and Brandt, 2015[4]; Dato, 2017[15]), there is no evidence of the relationships with air conditioning adoption.
There is strong evidence that households who care about reducing cost for energy have more incentives to invest in energy conservative measures like thermal insulation (Ameli and Brandt, 2015[4]). It is, instead, ambiguous the effects of the household's concern and attitude towards environment. Ameli and Brandt (2015)[4] suggest no correlation with both being pro-environment and understanding climate change's consequences. Dato (2017)[15] finds a negative relationship with both the concern related to climate change and that one related to resource depletion, but no correlation for the general environmental concern. Both contributions suggest that the investment decision in energy efficiency is influenced by the commitment in a charity non-governmental organisation (NGO), rather than in an environmental NGO.
Figure 2 shows the correlations between air conditioning adoption and the attitudinal variables. On the one hand, there is a negative correlation with the two environmental indexes and the commitment in an environmental NGO. Households that are environmentally friendly and aware seem to be less motivated to adopt air conditioning. On the other hand, there is a posi-

tive correlation with the energy behaviour index. While we expect a negative correlation since an air conditioner is not an energy conservative measure, this might suggest a so-called rebound effect. A low-cost energy oriented consumer might decide to install at least an air conditioner, because he/she is more confident of not exceeding in energy costs. For thermal insulation, instead, Figure 2 displays that there is a positive correlation with the energy behaviour index, in line with Ameli and Brandt (2015)[4]. Moreover, the positive relationship with the environmental attitude index might suggest that an environmentally-friendly household has a proactive behaviour for this technology. Finally, the correlation with both membership in an environmental NGO and environmental concern index results to be negative.

4 Results

The two choices of adopting air conditioning and thermal insulation are estimated independently using univariate probit regressions[6]. Table 3 reports the coefficients and the marginal effects of the explanatory variables on the adoption of air conditioning. Marginal effects are evaluated at variables' sample means. All regressions are run with robust standard errors and they include country fixed effects accounting for unobservable country-specific factors, such as prices. Our main specification includes the wealth index. Results using income are available in the Appendix Table B.2 [7].

Regarding Hypothesis 1, climate variables play a relevant role in the decision of adopting air conditioning, whereas they do not affect the choice of improving thermal insulation. Thermal insulation does not seem to be an adaptation strategy that households autonomously exploit to cope neither with warm nor with cold climate. This is in contrast with previous results such as in Gillingham et al (2012) [25], finding that thermal insulation is more likely to be present in colder areas. However, their analysis is limited to California (US). When we conduct a separate analysis for European and non-European countries, we also find that exposure to high CDDs and HDDs raises the probability of adoption in Europe, see Section 4.3.

[6]Using a bivariate probit model, we test the hypothesis of a joint decision of adopting both thermal comfort technologies, which we reject.

[7]Home size is not used as covariate because it is used in formulating the wealth index. Home owner and home type are, instead, included since for the wealth index's build we only used combinations of these two variables, namely apartment ownership and detached house ownership. The former excludes all tenants and owners of a detached house. The latter excludes all tenants and owners of an apartment.

Exposure to a warmer climate raises the probability that a household adopts air conditioning. Indeed, the linear term of CDDs is strongly and positively related to the technology decision in both regressions. This is consistent with the previous contributions (e.g. Sailor and Pavlova, 2003[48]; Biddle, 2008[10]; Rapson, 2014[46]; Davis and Gertler, 2015[16]). The squared CDD term is negative, while the interaction term between CDDs and HDDs is positive. The former term reduces the impact of an increase in CDDs on AC adoption as saturation increases. The latter raises the CDDs impact as a household living in areas with high HDDs is less used to high temperatures. Figure 3 displays the nonlinear AC saturation curve, as function of CDDs, for different values of HDDs. The curve shape is in line with previous studies (e.g. Sailor and Pavlova, 2003[48]; McNeil and Letschert, 2008[42]), but it also shows that the saturation curve varies significanlty with the indoor acclimatisation effect, depending on the extent and magnitude of the cold season as measured by HDDs. The plot suggests that households' habits for dwelling cooling and heating is a determinant of the choice of adopting air conditioning. If two households have the same level of CDDs, say 500, that one with the highest level of HDDs is more likely to adopt air conditioning. In addition, for households who are highly exposed to cold climate, say HDD = 4000, an increase in CDDs has a stronger effect on the adoption of air conditioning compare to a household who is less exposed to cold climate, say HDD = 2000.[8]

Overall, a 1% increase in CDDs raises the probability of adopting air conditioning by 0.12% (assuming HDD takes the mean value in our sample of 2726 degree days). This might appear a small number, but consider that the historical average increase in CDDs over all households observed in our sample over the last 30 years is +100%, which implies a higher probability of 12%. As another example, if the climate in the Netherlands, with average CDDs equal to 56, was to shift towards the average climate in France, with average CDDs equal to 198, the 254% increase in average CDDs would raise the average probability of adoption by 30%.

Regarding the second hypothesis, our evidence suggests that socio-economic characteristics are relevant drivers of both adoption decisions. The wealth in-

[8]We have plotted the interaction term since we cannot interpret it only focusing on its marginal effect. In nonlinear model, as a probit regression, the magnitude of an interaction effect does not coincide with the marginal effect of the interaction term (Ai and Norton, 2003[2]). We studied the interaction effect in two steps. First, after each regression we conducted a Wald test to test whether the coefficient of the interaction term is equal to 0. For both the regressions, the Wald test rejects the null hypothesis at the level of significance $\alpha = 0.01$. Second, using the *margins* command in Stata, we plotted the predictive margins in Figure 3.

dex is a strongly significant and positive determinant in both regressions. An increase in the wealth index by 1% (or by 1 standard deviation, being a normalized index), raises the probability of adopting air cooling by 11% whereas the probability of better insulating the house go up by 23%. These are large effects, but consider that wealth is relatively stable over time. Even comparing the different countries in our sample, average wealth varies between 0.26 in the Netherlands and -0.45 in Japan, a variation equal to 0.71. In both cases results are in line with previous contributions (Biddle, 2008[10]; Rapson, 2014[46]; McNeil and Letschert, 2008[42]; Davis and Gertler, 2015[16], Gillingham et al., 2012[25]; Ameli and Brandt, 2015[4]).
We observe that living in an urban area significantly increases the probability of adopting air conditioning (Hypothesis 3). As a household decides to move its primary residence from a rural area to an urban area, the probability of adopting air conditioning increases by about 6%. Contrary to air conditioning, living in an urban area does not seem to influence the thermal insulation adoption, as found in Ameli and Brandt (2015)[4]. Considering that perceived CDDs are generally higher in urban centers due to heat island effects, households seem to respond with investments that are feasible over a shorter period of time and might have lower institutional barriers.
Focusing on housing characteristics (Hypothesis 4), home tenure, ownership as well as home type influence at the adoption decisions regarding both air conditioning and thermal insulation. As the housing tenure increases by 1%, the probability of adopting air conditioning increases between 0.15%. Similar to Gillingham et al. (2012)[25] and Ameli and Brandt (2015)[4], housing tenure has a negative marginal effect on thermal insulation adoption, with a magnitude of about 0.2%. Owners have more incentives and less constraints than tenants to invest in thermal insulation, and moving from housing tenancy to ownership, for a household the probability of adopting the technology increases by 11.4%. This is in line with previous works (Gillingham et al., 2012[25]; Ameli and Brandt, 2015[4]; Kriström and Krishnamurthy, 2014[37]). Households living in an apartment are more likely to invest in thermal insulation as well as invest in air conditioning. The former result is unexpected compared to previous studies (e.g. Ameli and Brandt, 2015[4] , but it could be due to the selection of countries being analyzed, where there might exist energy policies and facilities that ease the installation of this energy-efficient technology in multi-dwelling houses. Moreover, thermal insulation adoption could be easier in an apartment, because installation costs can be smeared among all the households living in the building.
Even after controlling for climate and socio-economic characteristics, our results suggest that behaviours and attitudes (Hypothesis 5) matter and do affect households' choices. Energy conservation-oriented consumers are less

likely to buy new air conditioners whereas they are more likely to rely on thermal insulation. While the environmental attitude index negatively affects the probability of adopting air conditioning, adopting thermal insulation is being influenced by environmental concerns[9]. Being member of an environmental NGO does not seem to imply common preferences regarding these two forms of adaptation strategies. The implication is that policy designed to encourage energy-conservation measures as well as information campaigns might actually play an important role in influencing adaptation behaviours with significant energy implications.

Our estimates also suggest that some demographic structures of the household are important for the technology decision. The presence of minors in the household is an important driver of the decision for air conditioning. As the share of minors increases by 1%, the probability of adopting air conditioning increases by about 14%. Air conditioning adoption appears as a households' adaptation strategy to protect minors from the exposure to hot climate[10]. Family size is negatively related to the probability of adopting air conditioning as well as thermal insulation, which might point at the issue of credit constraints. Gender and age seem to affect only decisions related to thermal insulation. While for both family size and age the results are in line with Biddle (2008), the non-significance of education is in contrast with the same previous contribution[11]. The non-significance of the share of minors is in line with Gillingham et al. (2012)[25] findings.

4.1 Robustness analysis

In Appendix A, we report additional regressions that we run to test the robustness of our main results.

Since the existing literature has used income as socio-economic driver, we also run two specifications with household income as opposed to wealth. Table B.2 confirms most results, even though we lose almost 1000 observations. Income remains an important driver, with a larger impact in magnitude in the thermal insulation regression. Climate remains a significant determinants of

[9]We recall that the environmental attitude index measures households' approach towards environmental issues (e.g. sceptic or altruistic), while the environmental concern index quantifies how much households are concerned for specific environmental issues.

[10]Deschênes and Greenstone (2011)[22] find that infants are the most exposed to change in climatic conditions. As temperatures increase, they predict an annual mortality rates increase by 5.5% for female and by 7.8% for male in US.

[11]To our knowledge, Biddle (2008)[10] is the only contribution which includes demographic variables to study air conditioning adoption (AC room and central units adoption between 1955–1980).

air conditioning only, whereas as in the wealth regression, thermal insulation does not respond to different climatic conditions. Dwelling characteristics show similar patterns to the main results. House ownership is added as covariate and as expected it is highly significant either for air conditioning adoption than thermal insulation adoption[12]. Attitudinal characteristics and NGO membership emerge as relatively more significant determinants of both adaptation types, again suggesting a potentially high impact of policy on adaptation decisions.

As an additional robustness test, we estimate the adoption decision equations for European and non-European countries. The Europe (EU) group includes France, Netherlands, Spain, Sweden and Switzerland. The Non-Europe (NON-EU) group includes Australia, Japan and Canada[13].

Table B.3 and Table B.4 display the coefficients and the marginal effects of the explanatory variables for the two country groups on the adoption of respectively air conditioning and thermal insulation. The estimates suggest that only in the EU countries, households significantly adopt air conditioning to cope with the exposure to warmer climate. This is in line with trends in CDDs over the last 30 years for the included EU countries. For instance, in the same period, Sweden and Netherlands registered an increase in CDDs by respectively 307% and 317%. However, the adaptation to higher temperatures through air conditioning adoption is still very slow. The AC saturation rate in the EU group is on average, around 22%. As IEA (2018)[29] suggests, European countries are usually less inclined to adopt this cooling technology. The negative sign of the interaction term likely captures this cultural attitude, which slows down the air conditioning adoption. Moving to the NON-EU countries, CDDs are not significant. The CDD non-significance is likely due to the already high AC saturation rates in the extra-EU countries (on average, more than 65%, [29]). Results also show that in the EU sub-sample climate variable plays an important role in the decision of installing thermal insulation, and that thermal insulation adoption increases with the number of CDDs and mean level of HDDs, whereas for low HDDs levels, the negative effect would prevail. Figure 4 plots the predictive margins for air conditioning and thermal insulation as a function of CDDs, and it shows that marginal effect of climate on thermal insulation is smaller than that on air conditioning, whereas the opposite holds for wealth.

Finally, we also test whether results hold across income groups, and split the sample into a low and high wealth group, using the median of the wealth

[12] in the regression with the wealth index ownership is used to construct it

[13] We have not analyzed each country, since this leads to small sub-samples that reduce the statistical power of the regressions significantly. For the same reason we run the probit regressions using only the wealth index, which enable us to add almost 1000 observations.

index [14], namely "Low-Medium wealth" and "Medium-High wealth". Tables B.5 and B.6 provide the coefficients and the marginal effects of the explanatory variables for the two wealth groups on the decisions of installing the thermal comfort technologies. The outcomes suggest that poorer people are more sensitive to changes in socio-economic characteristics, especially for thermal insulation. Household size is also strongly and more negatively correlated with technology adoption in the low wealth group. Both results seem to indicate an issue of credit constraint. Regarding the behavioural and attitudinal characteristics, we find that they tend to have a larger impact among more wealthy households.

5 Conclusions

According to IEA (2018)[29], global demand for residential cooling will keep growing for the next decades and the increasing energy-use for space cooling is putting under strain the electricity supply of many countries. Improving thermal insulation of buildings is increasingly being recognized as an important adaptation option with mitigation co-benefits, and several countries mention this strategy as a way to reduce vulnerability to climate change as well as the energy use and costs (Davide et al. 2018, [19]).

Here we empirically confirm that, as previously suggested (Hallegatte et al. 2007)[27]), households tend to rely more on reactive adaptation strategies, such as air conditioning, rather proactive adaptation, such as thermal insulation, which is more costly, to adapt to different climatic conditions across and within countries.

Air conditioning is easier and cheaper to install, while thermal insulation adoption requires structural changes of the buildings, which are substantially more expensive, especially in existing buildings. This might suggest that for the sample of countries considered, current climate and energy policies might have not been sufficiently effective in supporting energy efficency improvements. Indeed a different result emerges when the analysis is restricted to European countries, where climate and energy policies, including financial support for renovating buildings are more widespread. Moreover, we also find that the impact of behavioural and attitudinal characteristics on the use of air conditioning and thermal insulation is relatively stronger in the European countries.

Our study is not without caveats. Although we are able to identify the role of several determinants of adaptation decisions - ranging from climate

[14] In this case as well, we run the probit regressions using only the wealth index to avoid too small subsamples.

factors, to socio-economic variables, households' characteristics and demographic variables, we are not able to explicitly and directly measure the impact of policies. For example, the survey contains questions regarding the presence of financial incentives for investing in thermal insulation, but missing values prevent us from using those data. Other explanatory variables that could be expected to play an important role include air conditioning prices as well as institutional barriers that could affect thermal insulation decisions. Studies using repeated cross-sectional data could attempt at evaluating the role of policy as well. This work contributes to the empirical evidence on the extensive margin. Future work will look at both the intensive and extensive margin.

References

[1] Aebischer, B., Catenazzi, G., Jakob, M. (2007). Impact of climate change on thermal comfort, heating and cooling energy demand in Europe. In *Proceedings eceee* (pp. 23-26).

[2] Ai, C., Norton, E. C. (2003). Interaction terms in logit and probit models. *Economics letters*, 80(1), 123-129.

[3] Ameli, N., Brandt, N. (2015). What Impedes Household Investment in Energy Efficiency and Renewable Energy?. *OECD Economic Department Working Papers*, (1222), 1.

[4] Ameli, N., Brandt, N. (2015). Determinants of households' investment in energy efficiency and renewables: evidence from the OECD survey on household environmental behaviour and attitudes. *Environmental Research Letters*, 10(4), 044015.

[5] Akpinar-Ferrand, E., Singh, A. (2010). Modeling increased demand of energy for air conditioners and consequent CO2 emissions to minimize health risks due to climate change in India. *Environmental science and policy*, 13(8), 702-712.

[6] Auffhammer, M., Hsiang, S. M., Schlenker, W., Sobel, A. (2013). Using weather data and climate model output in economic analyses of climate change. *Review of Environmental Economics and Policy*, 7(2), 181-198.

[7] Auffhammer, M. (2014). Cooling China: The weather dependence of air conditioner adoption. *Frontiers of Economics in China*, 9(1), 70-84.

[8] Auffhammer, M., Mansur, E. T. (2014). Measuring climatic impacts on energy consumption: A review of the empirical literature. *Energy Economics*, 46, 522-530.

[9] Auffhammer, M., Aroonruengsawat, A. (2011). Simulating the impacts of climate change, prices and population on California's residential electricity consumption. *Climatic change*, 109(1), 191-210.

[10] Biddle, J. (2008). Explaining the spread of residential air conditioning, 1955–1980. *Explorations in Economic History*, 45(4), 402-423.

[11] Bosello, F., Carraro, C., De Cian, E. (2013). Adaptation can help mitigation: an integrated approach to post-2012 climate policy. Environment and Development Economics, 18(3), 270-290.

[12] Brown, Z. (2014). Greening Household Behaviour: Crossdomain Comparisons in Environmental Attitudes and Behaviours Using Spatial Effects. *OECD Environment Working Papers*, No. 68, OECD Publishing, Paris. http://dx.doi.org/10.1787/5jxrclsj8z7b-en

[13] Burke, M., Craxton, M., Kolstad, C. D., Onda, C., Allcott, H., Baker, E., Barrage, L., Carson, R., Gillingham, K., Graf-Zivin, J., Greenstone, M., Hallegatte, S., Hanemann, W. M., Heal, G., Hsiang, S., Jones, B., Kelly, D. L., Kopp, R., Kotchen, M., Mendelsohn, R., Meng, K., Metcalf, G., Moreno-Cruz, J., Pindyck, R., Rose, s., Rudik, I., Stock, J., Tol, R. S. J. (2016). Opportunities for advances in climate change economics. *Science*, 352(6283), 292-293.

[14] Cohen, F., Glachant, M., Söderberg, M. (2017). *The cost of adapting to climate change: evidence from the US residential sector* (No. 263). Grantham Research Institute on Climate Change and the Environment.

[15] Dato, P. (2017). Investment in Energy Efficiency, Adoption of Renewable Energy and Household Behaviour: Evidence from OECD countries. In *Meeting the Energy Demands of Emerging Economies*, 40th IAEE International Conference, June 18-21, 2017. International Association for Energy Economics.

[16] Davis, L. W., Gertler, P. J. (2015). Contribution of air conditioning adoption to future energy use under global warming. *Proceedings of the National Academy of Sciences*, 201423558.

[17] De Cian, E., Lanzi, E., Roson, R. (2007). The impact of temperature change on energy demand: a dynamic panel analysis. *SSRN Electronic Journal.*

[18] De Cian, E., Sue Wing, I. (2017). Global energy consumption in a warming climate. *Environmental and Resource Economics*, 1-46.

[19] Davide, M., De Cian, E., Bernigaud, A. (2018). Energy for adaptation: connecting the Paris Agreement with the Sustainable Development Goals *Working Papers from Department of Economics, University of Venice "Ca' Foscari"*, No 2018:25.

[20] Dell, M., Jones, B. F., Olken, B. A. (2014). What do we learn from the weather? The new climate-economy literature. *Journal of Economic Literature*, 52(3), 740-98.

[21] Deschênes, O., Greenstone, M. (2007). The economic impacts of climate change: evidence from agricultural output and random fluctuations in weather. *American Economic Review*, 97(1), 354-385.

[22] Deschênes, O., Greenstone, M. (2011). Climate change, mortality, and adaptation: Evidence from annual fluctuations in weather in the US. *American Economic Journal: Applied Economics*, 3(4), 152-185.

[23] Erbs, D. G., Klein, S. A., Bechman, W. A. (1983). Estimation of degree-days and ambienttemperature bin data from monthly-average temperatures. *ASHARE Journal*, 25(6), 60-65.

[24] Filmer, D., Pritchett, L. H. (2001). Estimating Wealth Effects without Expenditure Data-or Tears: An Application to Educational Enrollments in States of India. *Demography*, 38(1), 115-132

[25] Gillingham, K., Harding, M., Rapson, D. (2012). Split incentives in residential energy consumption. *The Energy Journal*, 37-62.

[26] Greene, W. H. (2003). Econometric analysis. Pearson Education India.

[27] Hallegatte, S., Hourcade, J. C., Ambrosi, P. (2007). Using climate analogues for assessing climate change economic impacts in urban areas. *Climatic change*, 82(1-2), 47-60.

[28] International Energy Association. (2004). Energy Use in the New Millennium: Trends in IEA Countries. https://www.iea.org/publications/freepublications/publication/millennium.pdf

[29] International Energy Association. (2018). The future of cooling. https://www.iea.org/publications/freepublications/publication/The_Future_of_Cooling.pdf

[30] Nakicenovic, N., Alcamo, J., Grubler, A., Riahi, K., Roehrl, R. A., Rogner, H. H., Victor, N. (2000). *Special report on emissions scenarios (SRES), a special report of Working Group III of the intergovernmental panel on climate change*. Cambridge University Press. http://pure.iiasa.ac.at/id/eprint/6101/2/sres-en.pdf

[31] Intergovernmental Panel on Climate Change (2013). Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the

Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf

[32] Intergovernmental Panel on Climate Change (2014). Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.
https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/ar5_wgII_spm_en.pdf

[33] Intergovernmental Panel on Climate Change (2014). Climate Change 2014: Synthesis Report. *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
http://ar5-syr.ipcc.ch/ipcc/ipcc/resources/pdf/IPCC_SynthesisReport.pdf

[34] Isaac, M., Van Vuuren, D. P. (2009). Modeling global residential sector energy demand for heating and air conditioning in the context of climate change. *Energy policy*, 37(2), 507-521.

[35] Kahn, M. E. (2016). The climate change adaptation literature. *Review of Environmental Economics and Policy*, 10(1), 166-178.

[36] Krishnamurthy, C. K. B., Kriström, B. (2015). A cross-country analysis of residential electricity demand in 11 OECD-countries. *Resource and Energy Economics*, 39, 68-88.

[37] Kriström, B., Krishnamurthy, C. K. B. (2014). Greening Household Behaviour and Energy. *OECD Environment Working Papers*, No. 78, OECD Publishing, Paris. http://dx.doi.org/10.1787/5jxrclm3qhr0-en

[38] Mansur, E. T., Mendelsohn, R., Morrison, W. (2008). Climate change adaptation: A study of fuel choice and consumption in the US energy sector. *Journal of Environmental Economics and Management*, 55(2), 175-193.

[39] McFadden, D. (1973). Conditional logit analysis of qualitative choice behavior. In *Frontier in Econometrics*, ed. P. Zarembka. New York: Academic Press.

[40] McFadden, D. (1981). Econometric models of probabilistic choice. *Structural analysis of discrete data with econometric applications, 198272.*

[41] McFadden, D. L. (1984). Econometric analysis of qualitative response models. *Handbook of econometrics*, 2, 1395-1457.

[42] McNeil, M. A., Letschert, V. E. (2008). *Future Air Conditioning Energy Consumption in Developing Countriesand what can be done about it: The Potential of Efficiency in the Residential Sector* (No. LBNL-63203). Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA (US).

[43] McNeil, M. A., Letschert, V. E. (2010). Modeling diffusion of electrical appliances in the residential sector. *Energy and Buildings*, 42(6), 783-790.

[44] Mendelsohn, R. (2007). Measuring climate impacts with cross-sectional analysis. *Climatic Change*, 81(1), 1-7.

[45] Organization for Economic Co-operation and Development (2014). Greening Household Behaviour: Overview from the 2011 Survey – Revised edition, OECD Studies on Environmental Policy and Household Behaviour, OECD Publishing.
http://dx.doi.org/10.1787/9789264214651-en

[46] Rapson, D. (2014). Durable goods and long-run electricity demand: Evidence from air conditioner purchase behavior. *Journal of Environmental Economics and Management*, 68(1), 141-160.

[47] Rodell, M., Houser, P. R., Jambor, U. E. A., Gottschalck, J., Mitchell, K., Meng, C.-J., Arsenault, K., Cosgrove, B., Radakovich, J., Bosilovich, M., Entin, J. K., Walker, J. P., Lohmann, D., Toll, D. (2004). The global land data assimilation system. *Bulletin of the American Meteorological Society*, 85(3), 381-394.

[48] Sailor, D. J., Pavlova, A. A. (2003). Air conditioning market saturation and long-term response of residential cooling energy demand to climate change. *Energy*, 28(9), 941-951.

[49] Santamouris, M. (2016). Cooling the buildings–past, present and future. *Energy and Buildings*, 128, 617-638.

[50] Serret, Y., Brown, Z. (2014). Greening Household Behaviour: Overview of Results from Econometric Analysis and Policy Implications. *OECD Environment Working Papers*, No. 79, OECD Publishing, Paris. http://dx.doi.org/10.1787/5jxrcllt1kq5-en

[51] Vyas, S., Kumaranayake, L. (2006). Constructing socio-economic status indices: how to use principal components analysis. *Health policy and planning*, 21(6), 459-468.

Tables and Figures

Table 1: Description of variables

Variables	Type	Description
Dependent variables		
Air conditioning (Yes = 1)	Binary	Household has at least an electric air conditioner
Thermal insulation (Yes = 1)	Binary	Household has implemented thermal insulation
Climate		
Mean HDD (1986-2011)	Continuous	Mean heating degree days (1986-2011)
Mean CDD (1986-2011)	Continuous	Mean cooling degree days (1986-2011)
Socio-economic characteristics		
Wealth index	Continuous	Household's wealth index
Income (euro)	Continuous	Household's annual income in 2007 euros
Occupation	Categorical	Employment status or, if employed, occupation
Home size (m^2)	Continuous	Home size in squared meters
Home tenure	Continuous	Number of years lived in the primary residence
Urban area (Yes = 1)	Binary	Living in a urban area
Home owner (Yes = 1)	Binary	Household owns current primary residence
Home type (Apart. = 1)	Binary	Primary residence type
Demographics		
Age	Continuous	Household head's age
Household size	Continuous	Number of people living in the household
Share of under 18	Continuous	Share of minors in the household
Years post-secondary edu.	Continuous	Number of years of post-high school education
Gender (Male = 1)	Binary	Household head's gender
Attitudinal characteristics		
Envt. Attitude Index	Ordinal	Index summarising household's envt. attitudes
Energy Behav. Index	Ordinal	Index summarising household's energy-saving behav.
Envt. Concern Index	Ordinal	Index summarising household's envt. concerns
Member Envt. NGO (Yes = 1)	Binary	Household's membership in an envt. organisation

Table 2: Summary statistics by country for all variables. Mean values and standard deviation.

	Australia	Canada	France	Japan	Netherlands	Spain	Sweden	Switzerland	**Total**
Dependent variables									
Air conditioning (Yes = 1)	0.726	0.485	0.137	0.899	0.136	0.518	0.158	0.075	0.367
	(0.446)	(0.5)	(0.344)	(0.302)	(0.343)	(0.5)	(0.365)	(0.264)	(0.482)
Thermal insulation (Yes = 1)	0.551	0.380	0.458	0.26	0.561	0.325	0.337	0.419	0.431
	(0.498)	(0.486)	(0.498)	(0.439)	(0.496)	(0.469)	(0.473)	(0.494)	(0.495)
Climate									
Mean HDD (1986-2011)	1072.395	4431.25	2385.437	2138.938	2838.74	1601.623	4196.491	3344.818	2726.133
	(599.483)	(847.316)	(434.427)	(718.728)	(88.508)	(518.141)	(545.368)	(774.926)	(1264.479)
Mean CDD (1986-2011)	569.466	134.04	198.296	703.258	56.161	589.968	22.219	93.008	273.499
	(435.458)	(82.479)	(132.457)	(243.531)	(18.392)	(295.398)	(12.325)	(53.899)	(322.358)
Socio-economic characteristics									
Wealth index	0.163	0.255	0.016	-0.448	0.265	-0.3	-0.271	-0.197	0
	(0.963)	(1.012)	(0.999)	(0.858)	(0.899)	(0.930)	(1.063)	(1.018)	(1.000)
Income (euro)	48252.15	41913.96	38288.59	52210.36	38833.70	29316.51	40971.36	62138.74	41734.12
	(27946.98)	(26406.75)	(17892.26)	(28744.52)	(16986.86)	(16366.08)	(18278.37)	(29581.09)	(23731.99)
Home size (m^2)	153.767	119.793	99.725	100.826	129.196	106.155	98.071	112.209	116.772
	(96.370)	(56.062)	(44.571)	(56.478)	(61.614)	(50.85)	(41.463)	(52.119)	(62.926)
Home tenure	9.402	10.769	12.847	18.913	16.073	13.851	10.091	10.925	12.790
	(11.257)	(12.415)	(13.837)	(16.395)	(14.835)	(12.94)	(11.821)	(11.639)	(13.522)
Urban area (Yes = 1)	0.806	0.726	0.472	0.689	0.474	0.621	0.546	0.387	0.593
	(0.396)	(0.446)	(0.499)	(0.463)	(0.5)	(0.485)	(0.498)	(0.488)	(0.491)
Home owner (Yes = 1)	0.616	0.639	0.61	0.585	0.683	0.796	0.578	0.374	0.636
	(0.487)	(0.481)	(0.488)	(0.493)	(0.465)	(0.403)	(0.494)	(0.484)	(0.481)
Home type (Apart. = 1)	0.130	0.262	0.386	0.366	0.196	0.738	0.538	0.642	0.378
	(0.337)	(0.44)	(0.487)	(0.482)	(0.397)	(0.44)	(0.499)	(0.48)	(0.485)
Demographics									
Age	42.374	43.604	43.092	44.495	45.085	41.533	42.801	40.347	43.129
	(14.12)	(14.247)	(14.102)	(10.515)	(13.695)	(12.709)	(13.669)	(13.364)	(13.629)
Household size	2.883	2.515	2.737	3.193	2.641	3.015	2.412	2.696	2.735
	(1.478)	(1.186)	(1.169)	(1.591)	(1.189)	(1.117)	(1.180)	(1.403)	(1.277)
Share of under 18	0.156	0.126	0.163	0.122	0.137	0.154	0.161	0.147	0.147
	(0.223)	(0.213)	(0.228)	(0.197)	(0.223)	(0.218)	(0.236)	(0.215)	(0.221)
Years post-secondary edu.	3.371	3.136	2.653	4.866	4.17	3.662	2.378	2.879	3.363
	(3.494)	(2.987)	(2.379)	(4.129)	(3.168)	(3.061)	(2.505)	(2.806)	(3.119)
Gender (Male = 1)	0.496	0.491	0.486	0.546	0.501	0.509	0.507	0.522	0.502
	(0.5)	(0.5)	(0.5)	(0.498)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)
Attitudinal characteristics									
Envt. Attitude Index	0.344	0.512	0.484	0.109	0.285	0.523	0.621	0.49	0.430
	(0.693)	(0.665)	(0.663)	(0.633)	(0.623)	(0.6)	(0.714)	(0.631)	(0.668)
Energy Behav. Index	7.924	7.111	7.944	7.031	7.063	8.424	5.492	6.73	7.327
	(1.662)	(1.764)	(1.613)	(1.936)	(1.752)	(1.421)	(1.814)	(1.792)	(1.892)
Envt. Concern Index	7.368	7.566	7.632	7.194	6.953	8.015	7.431	7.747	7.472
	(1.746)	(1.669)	(1.638)	(1.568)	(1.479)	(1.414)	(1.616)	(1.62)	(1.625)
Member Envt. NGO (Yes = 1)	0.091	0.1	0.085	0.023	0.118	0.098	0.109	0.228	0.102
	(0.287)	(0.3)	(0.278)	(0.15)	(0.323)	(0.297)	(0.312)	(0.42)	(0.303)
Observations	906	1014	1134	434	1253	951	754	372	6818

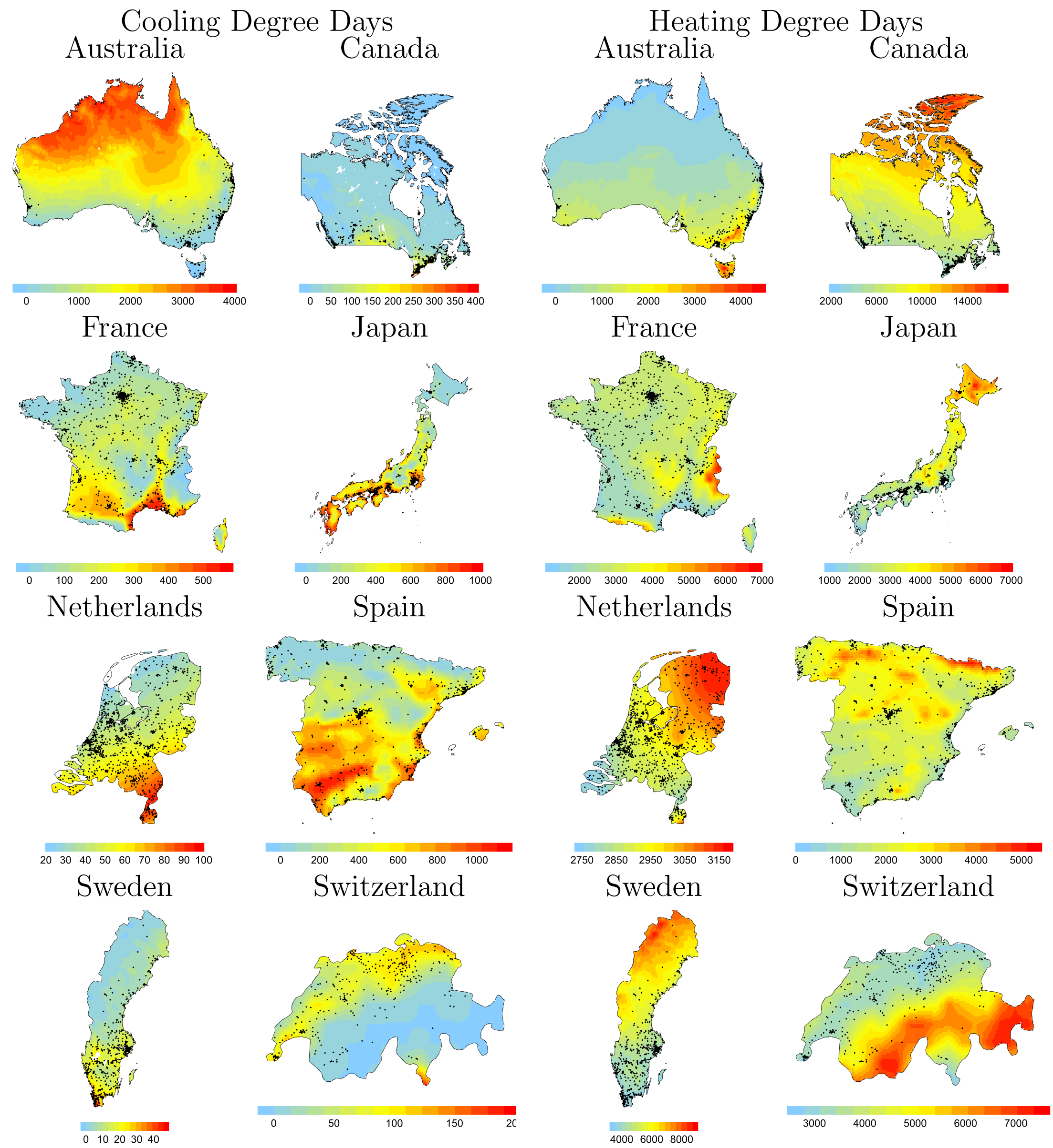


Figure 1: Cooling and Heating degree days. Long-term average 1986-2011

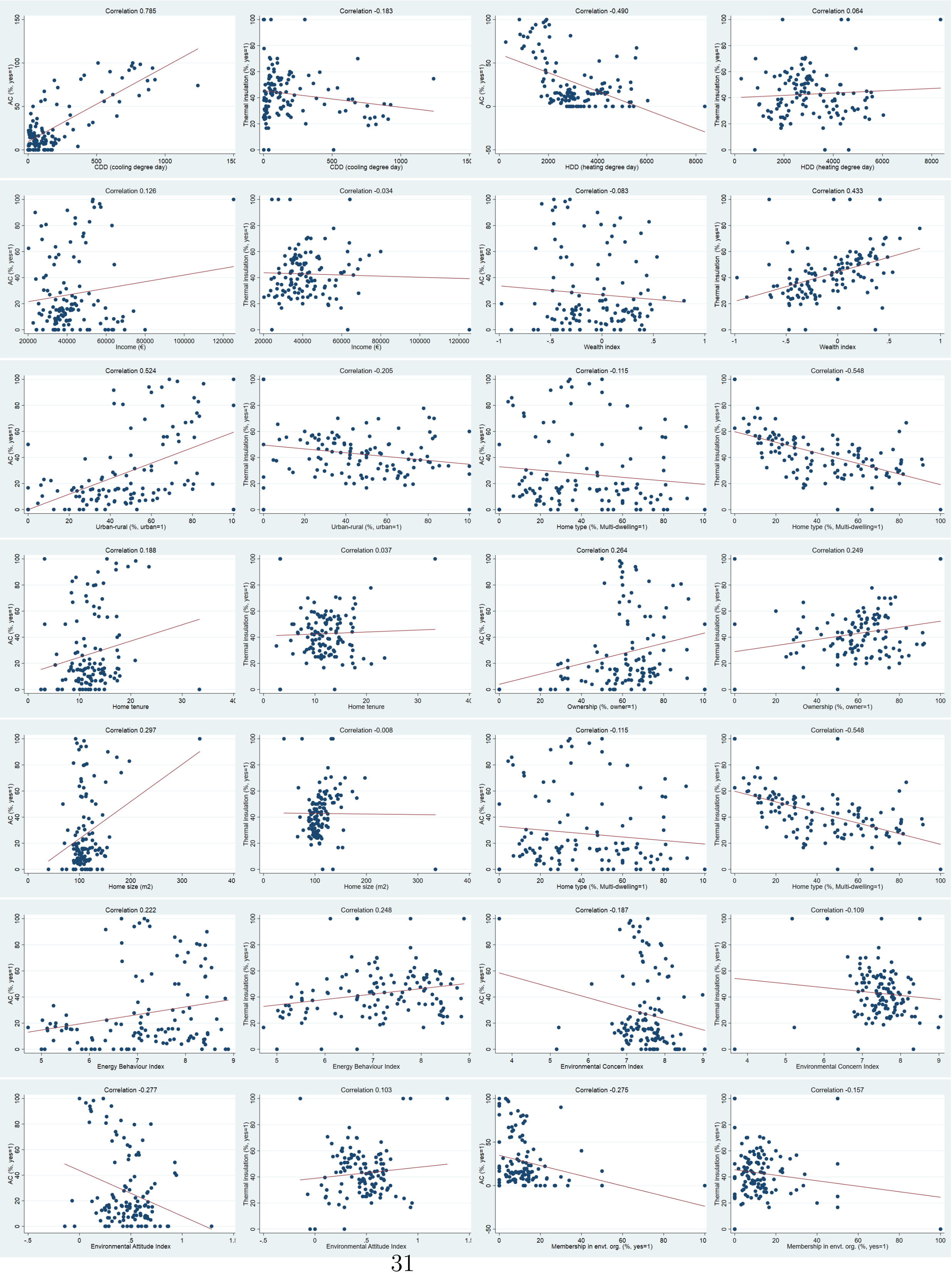


Figure 2: Correlation plots.

Table 3: Univariate probit regressions for full sample. Wealth index

Variable	Air conditioning		Thermal insulation	
	Coeff. (Sd. error)	M. effect (dy/dx) (Sd. error)	Coeff. (Sd. error)	M. effect (dy/dx) (Sd. error)
Climate				
Mean HDD (1986-2011)	7.07e-05*	2.57e-05*	-8.14e-08	-3.17e-08
	(4.27e-05)	(1.55e-05)	(3.96e-05)	(1.54e-05)
Mean CDD (1986-2011)	0.0013***	4.86e-04***	-3.72e-04	-1.45e-04
	(2.87e-04)	(1.05e-04)	(2.75e-04)	(1.07e-04)
CDD squared	-3.13e-07**	-1.14e-07**	1.75e-08	6.81e-09
	(1.39e-07)	(5.07e-08)	(1.35e-07)	(5.28e-08)
CDD x HDD	7.13e-07***	2.60e-07***	1.61e-07	6.27e-08
	(1.20e-07)	(4.36e-08)	(1.14e-07)	(4.44e-08)
Socio-economic charact.				
Wealth index	0.3028***	0.110***	0.6753***	0.263***
	(0.0280)	(0.0102)	(0.0265)	(0.0103)
Home tenure	0.0041***	0.0015***	-0.0053***	-0.0021***
	(0.0016)	(5.68e-04)	(0.0014)	(5.49e-04)
Urban area (Yes = 1)	0.1689***	0.0610***	-0.0295	-0.0115
	(0.0411)	(0.0147)	(0.0376)	(0.0147)
Home owner (Yes = 1)	0.0703	0.0255	0.2954***	0.114***
	(0.0470)	(0.0170)	(0.0426)	(0.0161)
Home type (Apart. = 1)	0.2387***	0.0878***	0.2397***	0.0938***
	(0.0561)	(0.0208)	(0.0498)	(0.0195)
Occupation				
Office worker	-0.0188	-0.0068	-0.0143	-0.0056
	(0.0585)	(0.0212)	(0.0548)	(0.0213)
Technical occupation	-0.0713	-0.0256	0.0923	0.0362
	(0.0734)	(0.0260)	(0.0678)	(0.0268)
Manual worker	-0.1023	-0.0365	0.0070	0.0027
	(0.0826)	(0.0289)	(0.0770)	(0.0301)
Unemployed	-0.0831	-0.0298	-0.1112	-0.0428
	(0.0795)	(0.0280)	(0.0780)	(0.0297)
Retired	-0.0066	-0.0024	0.0633	0.0248
	(0.0649)	(0.0236)	(0.0598)	(0.0235)
Other	-0.0307	-0.0111	-0.0577	-0.0224
	(0.0737)	(0.0265)	(0.0690)	(0.0266)
Demographics				
Age	-0.0024	-8.61e-04	0.0064***	0.0025***
	(0.0015)	(5.57e-04)	(0.0014)	(0.0005)
Household size	-0.0479**	-0.0174**	-0.0991***	-0.0386***
	(0.0214)	(0.0078)	(0.0192)	(0.0075)
Share of under 18	0.3880***	0.1413***	0.1418	0.0553
	(0.1115)	(0.0406)	(0.1010)	(0.0394)
Years post-secondary edu.	-0.0032	-0.0012	-0.0023	-0.0009
	(0.0064)	(0.0023)	(0.0059)	(0.0023)
Gender (Male = 1)	0.0551	0.0200	0.0685*	0.0267*
	(0.0395)	(0.0144)	(0.0359)	(0.0140)
Attitudinal charact.				
Envt. Attitude Index	-0.1367***	-0.0498***	-0.0235	-0.0092
	(0.0330)	(0.0120)	(0.0302)	(0.0118)
Energy Behav. Index	-0.0497***	-0.0181***	0.0789***	0.0307***
	(0.0113)	(0.0041)	(0.0103)	(0.0040)
Envt. Concern Index	0.0064	0.0023	0.0260**	0.0102**
	(0.0137)	(0.0050)	(0.0122)	(0.0048)
Member Envt. NGO (Yes = 1)	0.0669	0.0246	0.0866	0.0340
	(0.0629)	(0.0234)	(0.0585)	(0.0231)
Other				
Country fixed-effect	Yes		Yes	
Constant	-0.0103		-0.8053***	
	(0.2039)		(0.1888)	
Log pseudolikelihood	-3093.0185		-3748.5536	
Observations	6780		6780	

[a]Marginal effects at means of the dependent variable
[b]Robust standard error in parentheses
[c]*, ** and *** indicate p-value at 0.1, 0.05 and 0.01 significance level respectively

Figure 3: Predictive margins. Interaction term: CDDxHDD. Dependent variable: AC adoption. Wealth index regression from Table 3

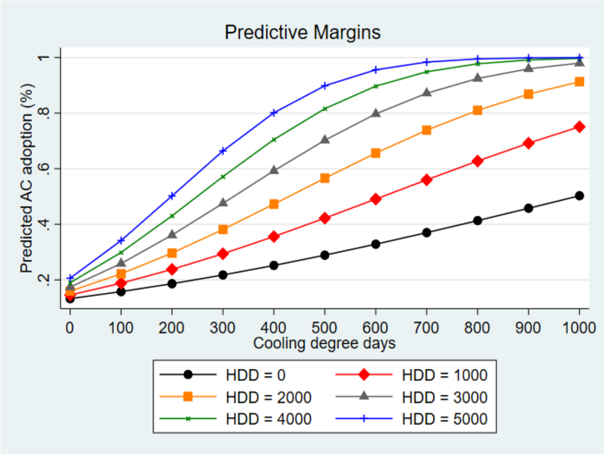
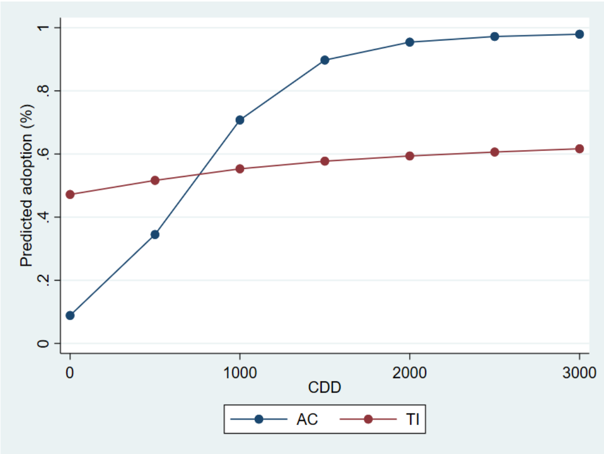


Figure 4: Predictive margins in Europe. Interaction term: CDDxHDD. Dependent variable: AC and Thermal insulation adoption. Wealth index regression from Tables B.3 and B.4



A Wealth index

Table A.1: PCA results for the wealth index

Variables	Factor score
Housing characteristics	
Home size	0.21045
Own Apartment	−0.10511
Own Detached house	0.24469
Vehicles	
Car	0.18569
Motorcycle	0.06126
Electric appliances	
Clothing dryer	0.18600
Fridge + Freezer	0.20200
Television (TV)	0.17324
Computer	0.12263
Internet connection	
Mobile phone with Internet access	0.02235
Skypecalls	0.03046
Energy-efficient appliances	
Top-rated energy-efficient appliances	0.13383
Ground-source heat pumps	0.08831
Solar panels	0.10620
Heat thermostats	0.14568
Wind turbines	0.08060
Energy-efficient windows	0.13827

B Robustness checks

Table B.2: Univariate probit regressions for full sample. Income

Variable	Air conditioning		Thermal insulation	
	Coeff. (Sd. error)	M. effect (dy/dx) (Sd. error)	Coeff. (Sd. error)	M. effect (dy/dx) (Sd. error)
Climate				
Mean HDD (1986-2011)	5.51e-05	2.07e-05	8.61e-06	3.36e-06
	(4.37e-05)	(1.64e-05)	(4.12e-05)	(1.61e-05)
Mean CDD (1986-2011)	0.0011***	4.12e-04***	-3.77e-04	-1.47e-04
	(2.94e-04)	(1.10e-04)	(2.81e-04)	(1.10e-04)
CDD squared	-2.35e-07	-8.81e-08	2.05e-08	8.01e-09
	(1.44e-07)	(5.41e-08)	(1.38e-07)	(5.41e-08)
CDD x HDD	6.85e-07***	2.57e-07***	1.10e-07	4.31e-08
	(1.24e-07)	(4.65e-08)	(1.16e-07)	(4.53e-08)
Socio-economic charact.				
Income (euro)	2.00e-06*	7.52e-07*	2.73e-06***	1.07e-06***
	(1.05e-06)	(3.96e-07)	(9.32e-07)	(3.64e-07)
Home size (m^2)	2.76e-04	1.04e-04	0.0019***	7.43e-04***
	(3.72e-04)	(1.40e-04)	(3.40e-04)	(1.33e-04)
Home tenure	0.0055***	0.0021***	-0.0048***	-0.0019***
	(0.0017)	(6.51e-04)	(0.0015)	(6.01e-04)
Urban area (Yes = 1)	0.1561***	0.0582***	-0.0723*	-0.0283*
	(0.0446)	(0.0165)	(0.0401)	(0.0157)
Home owner (Yes = 1)	0.2053***	0.0761***	0.5929***	0.224***
	(0.0484)	(0.0177)	(0.0438)	(0.0157)
Home type (Apart. = 1)	-0.0299	-0.0112	-0.3054***	-0.118***
	(0.0542)	(0.0203)	(0.0484)	(0.0184)
Occupation				
Office worker	-0.0091	-0.0034	-0.0155	-0.0061
	(0.0624)	(0.0234)	(0.0566)	(0.0221)
Technical occupation	-0.0958	-0.0355	0.0728	0.0286
	(0.0779)	(0.0284)	(0.0708)	(0.0279)
Manual worker	-0.0867	-0.0321	-0.0834	-0.0323
	(0.0895)	(0.0326)	(0.0811)	(0.0311)
Unemployed	-0.1267	-0.0466	-0.1769*	-0.0677**
	(0.0885)	(0.0318)	(0.0863)	(0.0323)
Retired	0.0102	0.0038	0.0477	0.0187
	(0.0721)	(0.0271)	(0.0653)	(0.0257)
Other	-0.0530	-0.0197	-0.0893	-0.0346
	(0.0786)	(0.0290)	(0.0723)	(0.0277)
Demographics				
Age	-0.0022	-8.29e-04	0.0059***	0.0023***
	(0.0017)	(6.27e-04)	(0.0015)	(0.0006)
Household size	0.0064	0.0024	0.0009	0.0004
	(0.0231)	(0.0087)	(0.0205)	(0.0080)
Share of under 18	0.3721***	0.1397***	0.0366	0.0143
	(0.1219)	(0.0457)	(0.1100)	(0.0430)
Years post-secondary edu.	-0.0066	-0.0025	-0.0007	-0.0003
	(0.0070)	(0.0026)	(0.0063)	(0.0024)
Gender (Male = 1)	0.1137***	0.0426***	0.1004***	0.0392***
	(0.0424)	(0.0158)	(0.0383)	(0.0149)
Attitudinal charact.				
Envt. Attitude Index	-0.1357***	-0.0509***	-0.0607*	-0.0237*
	(0.0354)	(0.0133)	(0.0319)	(0.0125)
Energy Behav. Index	-0.0418***	-0.0157***	0.0673***	0.0263***
	(0.0122)	(0.0046)	(0.0111)	(0.0043)
Envt. Concern Index	0.0037	0.0014	0.0211	0.0083
	(0.0146)	(0.0055)	(0.0132)	(0.0052)
Member Envt. NGO (Yes = 1)	0.0956	0.0363	0.1344**	0.0530**
	(0.0667)	(0.0256)	(0.0608)	(0.0241)
Other				
Country fixed-effect	Yes		Yes	
Constant	-0.2894		-1.336***	
	(0.2225)		(0.2054)	
Log pseudolikelihood	-2672.3527		-3377.6479	
Observations	5638		5638	

[a]Marginal effects at means of the dependent variable
[b]Robust standard error in parentheses
[c]*, ** and *** indicate p-value at 0.1, 0.05 and 0.01 significance level respectively

Table B.3: Univariate probit regression by country group. Dependent variable: the adoption of air conditioning. EU: France, Netherlands, Spain, Sweden and Switzerland. NON-EU: Australia, Japan and Canada.

Variable	EU		NON-EU	
	Coeff. (Sd. error)	M. effect (dy/dx) (Sd. error)	Coeff. (Sd. error)	M. effect (dy/dx) (Sd. error)
Climate				
Mean HDD (1986-2011)	2.7e-05	6.91e-06	1.63e-04***	5.74e-05***
	(8.28e-05)	(2.12e-05)	(5.39e-05)	(1.90e-05)
Mean CDD (1986-2011)	0.0041***	0.0010***	0.0003	0.0001
	(0.0010)	(0.0003)	(0.0003)	(0.0001)
CDD squared	-9.98e-07	-2.55e-07	9.57e-08	3.37e-08
	(6.73e-07)	(1.72e-07)	(1.63e-07)	(5.72e-08)
CDD x HDD	-7.01e-07**	-1.79e-07**	1.22e-06***	4.30e-07***
	(3.03e-07)	(7.76e-08)	(1.48e-07)	(5.24e-08)
Socio-economic charact.				
Wealth index	0.4234***	0.108***	0.1877***	0.0661***
	(0.0371)	(0.0093)	(0.0444)	(0.0156)
Home tenure	0.0056***	0.0014***	0.0016	0.0006
	(0.0020)	(0.0005)	(0.0026)	(0.0009)
Urban area (Yes = 1)	0.1536***	0.0392***	0.2189***	0.0789***
	(0.0521)	(0.0132)	(0.0705)	(0.0260)
Home owner (Yes = 1)	0.1217*	0.0306**	0.0263	0.0093
	(0.0633)	(0.0156)	(0.0755)	(0.0267)
Home type (Apart. = 1)	0.3645***	0.0945***	0.1588*	0.0546*
	(0.0760)	(0.0198)	(0.0893)	(0.0300)
Occupation				
Office worker	0.0273	0.0070	-0.0250	-0.0088
	(0.0756)	(0.0196)	(0.0934)	(0.0330)
Technical occupation	-0.0244	-0.0062	-0.0639	-0.0228
	(0.0959)	(0.0241)	(0.1191)	(0.0430)
Manual worker	-0.0621	-0.0155	-0.1078	-0.0387
	(0.1152)	(0.0280)	(0.1226)	(0.0449)
Unemployed	-0.0546	-0.0136	-0.076	-0.0272
	(0.1040)	(0.0254)	(0.1319)	(0.0478)
Retired	0.0668	0.0174	-0.0359	-0.0127
	(0.0860)	(0.0229)	(0.1004)	(0.0357)
Other	-0.0492	-0.0123	0.0077	0.0027
	(0.0951)	(0.0234)	(0.1284)	(0.0450)
Demographics				
Age	-0.0042**	-0.0011**	0.0005	0.0002
	(0.0020)	(0.0005)	(0.0024)	(0.0008)
Household size	-0.0863***	-0.0221***	5.45e-05	1.92e-05
	(0.0305)	(0.0078)	(0.0308)	(0.0108)
Share of under 18	0.4355***	0.111***	0.2795	0.0983
	(0.1480)	(0.0378)	(0.1787)	(0.0629)
Years post-secondary edu.	0.0102	0.0026	-0.0166*	-0.0059*
	(0.0092)	(0.0023)	(0.0088)	(0.0031)
Gender (Male = 1)	-0.0118	-0.0030	0.1598**	0.0562**
	(0.0515)	(0.0132)	(0.0634)	(0.0223)
Attitudinal charact.				
Envt. Attitude Index	-0.1716***	-0.0439***	-0.0790	-0.0278
	(0.0433)	(0.0110)	(0.0521)	(0.0183)
Energy Behav. Index	-0.0522***	-0.0133***	-0.0428**	-0.0151**
	(0.0154)	(0.0039)	(0.0170)	(0.0060)
Envt. Concern Index	0.0028	0.0007	0.0104	0.0037
	(0.0184)	(0.0047)	(0.0209)	(0.0074)
Member Envt. NGO (Yes = 1)	0.0853	0.0225	-0.0082	-0.0029
	(0.0802)	(0.0218)	(0.1027)	(0.0363)
Other				
Country fixed-effect	Yes		Yes	
Constant	-1.437		-0.2720	
	(0.3646)		(0.2976)	
Log pseudolikelihood	-1762.2017		-1258.0587	
Observations	4436		2344	

[a]Marginal effects at means of the dependent variable
[b]Robust standard error in parentheses
[c]*, ** and *** indicate p-value at 0.1, 0.05 and 0.01 significance level respectively

Table B.4: Univariate probit regression by country group. Dependent variable: the adoption of thermal insulation. EU: France, Netherlands, Spain, Sweden and Switzerland. NON-EU: Australia, Japan and Canada.

Variable	EU		NON-EU	
	Coeff. (Sd. error)	M. effect (dy/dx) (Sd. error)	Coeff. (Sd. error)	M. effect (dy/dx) (Sd. error)
Climate				
Mean HDD (1986-2011)	-7.48e-05	-2.93e-05	-1.38e-05	-5.31e-06
	(6.1e-05)	(2.38e-05)	(5.68e-05)	(2.19e-05)
Mean CDD (1986-2011)	-0.0022**	-8.51e-04**	-2.43e-04	-9.38e-05
	(9.05e-04)	(3.54e-04)	(3.36e-04)	(1.30e-04)
CDD squared	1.08e-06*	4.23e-07*	-6.29e-08	-2.43e-08
	(6.03e-07)	(2.36e-07)	(1.57e-07)	(6.04e-08)
CDD x HDD	9.02e-07***	3.53e-07***	-9.72e-08	-3.75e-08
	(2.84e-07)	(1.11e-07)	(1.41e-07)	(5.42e-08)
Socio-economic charact.				
Wealth index	0.7023***	0.275***	0.6486***	0.250***
	(0.0328)	(0.0129)	(0.0465)	(0.0180)
Home tenure	-0.0057***	-0.0022***	-0.0042*	-0.0016*
	(0.0017)	(0.0007)	(0.0025)	(9.71e-04)
Urban area (Yes = 1)	-0.0372	-0.0146	-0.0425	-0.0164
	(0.0454)	(0.0177)	(0.0688)	(0.0267)
Home owner (Yes = 1)	0.2558***	0.0990***	0.3420***	0.130***
	(0.0520)	(0.0199)	(0.0757)	(0.0280)
Home type (Apart. = 1)	0.3339***	0.130***	4.39e-04	1.69e-04
	(0.0611)	(0.0237)	(0.0915)	(0.0353)
Occupation				
Office worker	0.0218	0.0085	-0.0840	-0.0322
	(0.0680)	(0.0266)	(0.0941)	(0.0359)
Technical occupation	0.0684	0.0269	0.1538	0.0601
	(0.0829)	(0.0327)	(0.1205)	(0.0476)
Manual worker	0.1407	0.0556	-0.1895	-0.0713
	(0.0981)	(0.0390)	(0.1279)	(0.0467)
Unemployed	-0.0587	-0.0228	-0.2257	-0.0843
	(0.0933)	(0.0361)	(0.1472)	(0.0529)
Retired	0.0254	0.0100	0.1230	0.0478
	(0.0754)	(0.0296)	(0.1003)	(0.0392)
Other	-0.0291	-0.0114	-0.1077	-0.0410
	(0.0834)	(0.0325)	(0.1265)	(0.0474)
Demographics				
Age	0.0038**	0.0015**	0.0110***	0.0043***
	(0.0017)	(6.74e-04)	(0.0025)	(9.53e-04)
Household size	-0.0884***	-0.0346***	-0.1185***	-0.0457***
	(0.0256)	(0.0100)	(0.0297)	(0.0115)
Share of under 18	0.0827	0.0323	0.2814	0.109
	(0.1253)	(0.0490)	(0.1789)	(0.0690)
Years post-secondary edu.	-0.0011	-4.23e-04	-0.0048	-0.0018
	(0.0080)	(0.0031)	(0.0090)	(0.0035)
Gender (Male = 1)	0.0816*	0.0319*	0.0628	0.0242
	(0.0437)	(0.0171)	(0.0643)	(0.0248)
Attitudinal charact.				
Envt. Attitude Index	-0.0386	-0.0151	-0.0211	-0.0081
	(0.0373)	(0.0146)	(0.0529)	(0.0204)
Energy Behav. Index	0.0954***	0.0373***	0.0527***	0.0203***
	(0.0129)	(0.0051)	(0.0175)	(0.0067)
Envt. Concern Index	0.0287*	0.0112*	0.0290	0.0112
	(0.0154)	(0.0060)	(0.0205)	(0.0079)
Member Envt. NGO (Yes = 1)	0.0669	0.0263	0.1844	0.0722
	(0.0691)	(0.0272)	(0.1127)	(0.0446)
Other				
Country fixed-effect	Yes		Yes	
Constant	-0.9968***		-0.6663	
	(0.2920)		(0.3022)	
Log pseudolikelihood	-2483.6257		-1238.8761	
Observations	4436		2344	

[a]Marginal effects at means of the dependent variable
[b]Robust standard error in parentheses
[c]*, ** and *** indicate p-value at 0.1, 0.05 and 0.01 significance level respectively

Table B.5: Univariate probit regressions by wealth group. Dependent variable: the adoption of air conditioning

Variable	Low-Medium Wealth		Medium-High Wealth	
	Coeff. (Sd. error)	M. effect (dy/dx) (Sd. error)	Coeff. (Sd. error)	M. effect (dy/dx) (Sd. error)
Climate				
Mean HDD (1986-2011)	-2.47e-05	-8.32e-06	1.62e-04***	6.21e-05***
	(7.06e-05)	(2.38e-05)	(5.61e-05)	(2.15e-05)
Mean CDD (1986-2011)	0.0016***	5.42e-04***	9.96e-04***	3.81e-04***
	(5.34e-04)	(1.80e-04)	(3.59e-04)	(1.38e-04)
CDD squared	-4.18e-07	-1.41e-07	-1.95e-07	-7.45e-08
	(2.90e-07)	(9.76e-08)	(1.58e-07)	(6.06e-08)
CDD x HDD	7.30e-07***	2.46e-07***	7.27e-07***	2.78e-07***
	(1.88e-07)	(6.31e-08)	(1.61e-07)	(6.17e-08)
Socio-economic charact.				
Wealth index	0.3504***	0.1181***	0.2983***	0.1142***
	(0.0614)	(0.0207)	(0.0510)	(0.0196)
Home tenure	0.0018	0.0006	0.0065***	0.0025***
	(0.0025)	(0.0009)	(0.0020)	(0.0008)
Urban area (Yes = 1)	0.2545***	0.0832***	0.1247**	0.0477**
	(0.0649)	(0.0205)	(0.0548)	(0.0209)
Home owner (Yes = 1)	0.1283**	0.0435**	0.1124	0.0425
	(0.0616)	(0.0210)	(0.0809)	(0.0301)
Home type (Apart. = 1)	0.1015	0.0339	0.4528***	0.1781***
	(0.0725)	(0.0239)	(0.0935)	(0.0369)
Occupation				
Office worker	-0.0312	-0.0105	-0.0383	-0.0146
	(0.0907)	(0.0303)	(0.0777)	(0.0296)
Technical occupation	-0.1153	-0.0378	-0.0801	-0.0304
	(0.1165)	(0.0371)	(0.0958)	(0.0360)
Manual worker	-0.1261	-0.0411	-0.0930	-0.0352
	(0.1240)	(0.0391)	(0.1136)	(0.0424)
Unemployed	-0.0971	-0.0320	-0.1023	-0.0386
	(0.1115)	(0.0358)	(0.1207)	(0.0448)
Retired	0.0101	0.0034	-0.0406	-0.0155
	(0.0993)	(0.0336)	(0.0873)	(0.0331)
Other	-0.0292	-0.0098	-0.0210	-0.0080
	(0.1129)	(0.0375)	(0.0981)	(0.0374)
Demographics				
Age	0.0006	0.0002	-0.0049**	-0.0019**
	(0.0023)	(0.0008)	(0.0021)	(0.0008)
Household size	-0.0687**	-0.0232**	-0.0345	-0.0132
	(0.0321)	(0.0108)	(0.0302)	(0.0116)
Share of under 18	0.4111**	0.1386**	0.3709**	0.1419**
	(0.1670)	(0.0563)	(0.1528)	(0.0585)
Years post-secondary edu.	-0.0088	-0.0030	0.0006	0.0002
	(0.0094)	(0.0032)	(0.0090)	(0.0034)
Gender (Male = 1)	0.0514	0.0173	0.0604	0.0231
	(0.0580)	(0.0196)	(0.0548)	(0.0210)
Attitudinal charact.				
Envt. Attitude Index	-0.0162	-0.0055	-0.2403***	-0.0920***
	(0.0486)	(0.0164)	(0.0458)	(0.0176)
Energy Behav. Index	-0.0517***	-0.0174***	-0.0479***	-0.0183***
	(0.0166)	(0.0056)	(0.0158)	(0.0061)
Envt. Concern Index	0.0005	0.0002	0.0104	0.0040
	(0.0203)	(0.0069)	(0.0188)	(0.0072)
Member Envt. NGO (Yes = 1)	-0.0799	-0.0264	0.1824**	0.0710**
	(0.0987)	(0.0320)	(0.0828)	(0.0326)
Other				
Country fixed-effect	Yes		Yes	
Constant	-0.0747		0.0836	
	(0.3193)		(0.2924)	
Log pseudolikelihood	-1411.9783		-1636.3954	
Observations	3385		3395	

[a]Marginal effects at means of the dependent variable
[b]Robust standard error in parentheses
[c]*, ** and *** indicate p-value at 0.1, 0.05 and 0.01 significance level respectively

Table B.6: Univariate probit regressions by wealth group. Dependent variable: the adoption of thermal insulation

Variable	Low-Medium Group		Medium-High Group	
	Coeff. (Sd. error)	M. effect (dy/dx) (Sd. error)	Coeff. (Sd. error)	M. effect (dy/dx) (Sd. error)
Climate				
Mean HDD (1986-2011)	4.07e-05	1.18e-05	-3.06e-05	-1.15e-05
	(6.2e-05)	(1.80e-05)	(5.22e-05)	(1.97e-05)
Mean CDD (1986-2011)	-5.26e-04	-1.53e-04	-3.62e-04	-1.36e-04
	(5.10e-04)	(1.48e-04)	(3.45e-04)	(1.30e-04)
CDD squared	1.51e-07	4.39e-08	-4.06e-08	-1.53e-08
	(2.77e-07)	(8.02e-08)	(1.60e-07)	(6.02e-08)
CDD x HDD	3.56e-07*	1.03e-07*	2.13e-08	8.03e-09
	(1.95e-07)	(5.64e-08)	(1.45e-07)	(5.48e-08)
Socio-economic charact.				
Wealth index	0.8064***	0.2339***	0.6141***	0.2312***
	(0.0589)	(0.0168)	(0.0474)	(0.0178)
Home tenure	-0.0075***	-0.0022***	-0.0043**	-0.0016**
	(0.0023)	(0.0007)	(0.0018)	(0.0007)
Urban area (Yes = 1)	-0.0368	-0.0107	-0.0140	-0.0053
	(0.0577)	(0.0169)	(0.0500)	(0.0188)
Home owner (Yes = 1)	0.4280***	0.1274***	0.0880	0.0335
	(0.0560)	(0.0170)	(0.0714)	(0.0274)
Home type (Apart. = 1)	0.1703***	0.0483***	0.3243***	0.1155***
	(0.0648)	(0.0179)	(0.0883)	(0.0294)
Occupation				
Office worker	0.0686	0.0201	-0.0922	-0.0349
	(0.0850)	(0.0252)	(0.0712)	(0.0271)
Technical occupation	0.0563	0.0166	0.1059	0.0393
	(0.1051)	(0.0316)	(0.0900)	(0.0328)
Manual worker	0.0413	0.0121	-0.0378	-0.0143
	(0.1149)	(0.0342)	(0.1043)	(0.0397)
Unemployed	-0.0369	-0.0106	-0.1921*	-0.0741*
	(0.1129)	(0.0320)	(0.1086)	(0.0426)
Retired	0.0210	0.0061	0.0952	0.0355
	(0.0928)	(0.0272)	(0.0807)	(0.0297)
Other	-0.0698	-0.0198	-0.0489	-0.0185
	(0.1083)	(0.0300)	(0.0902)	(0.0344)
Demographics				
Age	0.0075***	0.0022***	0.0053***	0.0020***
	(0.0021)	(0.0006)	(0.0020)	(0.0007)
Household size	-0.1632***	-0.0473***	-0.0761***	-0.0287***
	(0.0304)	(0.0088)	(0.0261)	(0.0098)
Share of under 18	0.3440**	0.0998**	0.0645	0.0243
	(0.1576)	(0.0457)	(0.1343)	(0.0506)
Years post-secondary edu.	0.0025	0.0007	-0.0067	-0.0025
	(0.0087)	(0.0025)	(0.0082)	(0.0031)
Gender (Male = 1)	0.1152**	0.0334**	0.0462	0.0174
	(0.0533)	(0.0155)	(0.0492)	(0.0185)
Attitudinal charact.				
Envt. Attitude Index	-0.0087	-0.0025	-0.0288	-0.0108
	(0.0451)	(0.0131)	(0.0415)	(0.0156)
Energy Behav. Index	0.0738***	0.0214***	0.0858***	0.0323***
	(0.0154)	(0.0045)	(0.0141)	(0.0053)
Envt. Concern Index	0.0295	0.0086	0.0206	0.0078
	(0.0181)	(0.0052)	(0.0168)	(0.0063)
Member Envt. NGO (Yes = 1)	0.0987	0.0295	0.0798	0.0297
	(0.0886)	(0.0273)	(0.0779)	(0.0286)
Other				
Country fixed-effect	Yes		Yes	
Constant	-0.8237***		-0.4650*	
	(0.2885)		(0.2627)	
Log pseudolikelihood	-1649.5008		-2066.0446	
Observations	3385		3395	

[a]Marginal effects at means of the dependent variable
[b]Robust standard error in parentheses
[c]*, ** and *** indicate p-value at 0.1, 0.05 and 0.01 significance level respectively