Households'adaptation in a warming climate. Air conditioning and thermal insulation choices.

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Abstract

Adjustments in the final use of energy is a critical margin of adaptation for maintaining indoor thermal comfort. This paper explores how households have been adopting air conditioning and thermal insulation to cope with different climatic conditions, and how climatic factors interact with socio-economic, demographic, and household characteristics across eight OECD countries. Changes in the cumulative number of hot and cold days over the year, urbanization, demographics and household characteristics, including attitudes towards energy efficiency, strongly affect those two margins of adaptation, along with income. If the historically-observed adaptation behaviour is maintained also under future socio-economic pathways and climate scenarios, the impact of global warming and income on air conditioning adoption will be reinforced by urbanization trends, which on the contrary will make it more difficult to improve building thermal insulation.

JEL Codes: D12, O13, Q4

Keywords: Households, climate change, adaptation, energy, scenarios.

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1 Introduction

Limiting the increase in global temperature well below 2°C, as subscribed by the international community, requires unprecedented efforts, which are projected to be even greater for the most ambitious 1.5°C target. Scenario analysis and the recently published 1.5 IPCC Special Report emphasize the need for urgent mitigation action across all sectors (Rogelj et al. In press[62]). In this context, a rapid and significant reduction in the demand of energy is crucial for facilitating the transition away from fossil fuels, while achieving a range of sustainable development goals in a synergetic way (Grübler et al. 2018[25]). Energy consumption in buildings represents a key challenge as it accounts for a third of global energy demand, with space heating and cooling being the major end-use. Looking forward, expansion in residential energy demand is expected to be driven by cooling energy consumption (Levesque et al 2018[41]), although the steady diffusion of residential Air Conditioning (AC) remains one of the most critical blind spots in today's energy debate (IEA, 2018[31]). To what extent the increase in residential AC could set a drag on the energy transition remains overlooked in low-carbon scenarios.

By allowing households to maintain the desired level of thermal comfort in the residential environment, AC is a relatively low-cost and highly effective adaptation strategy. At the same time, AC adoption is an emblematic example of potential maladaptive response to climate change impacts (Barnett and O'Neill, 2010[8]). The trade-off with higher initial costs and uncertain long-term benefits of less energy-intensive alternative adaptation strategies, such as upgrading building standards or adapting the insulation of existing buildings, can result in a lock-in in AC widespread adoption (Hallegatte et al. 2007[28]), with potentially negative consequences for energy demand, carbon emissions, and increased vulnerability of physically- and mentally-accustomized individuals.

When it comes to AC future trends, a key concern are the emerging economies where a growing fraction of population is achieving income levels that make the adoption of this technology affordable. The location of these countries in the hottest areas of the world, along with above-average projected temperature increases as a result of climate change, are expected to amplify AC acquisition trends (IEA, 2018[31]). Existing studies indeed have highlighted the role of income, along with climate, as a critical driver (Sailor and Pavlova 2003[64], McNeil and Letschert 2010[47], Auffhammer, 2014[6][1], Davis and

[1] The author first uses panel data between 1995 and 2009 of 29 Chinese provinces about air condi-

Gertler, 2015[14][2], and Akpinar-Ferrand and Singh, 2010[2]).

As soon as income per capita rises above a certain threshold, its relative impact appears much weaker compared to other factors, such as the number of days with temperature above certain thresholds (IEA, 2018 [31]). Urbanization and age structure also play a critical role, especially in higher income countries. Heat-island effects intensify temperature in cities. Old people are more vulnerable and less tolerant to heat, but at the same time they tend to use less AC than younger generations. Families with children might be more inclined to invest in AC as they perceive larger benefits. AC ownership varies greatly across affluent countries, with the United States (US) and China together accounting for 58% of global air-conditioning units and Europe for only 6%, reflecting not only heterogeneity in climatic and income conditions, but also different urbanization patterns, demographic characteristics as well as cultural factors. Europeans, for example, have been less inclined to adopt AC compared to the Americans, but trends are changing especially in Southern Europe.

Contrary to AC adoption, improving the insulation of walls and roofs of buildings (henceforth Thermal Insulation, TI) is an example of adaptation option that, while reducing the vulnerability of human settlements, can support mitigation and provide co-benefits (Ebinger and Vergara 2011[19], Revi et al. 2014[60]). In the context of decarbonization pathways, Grübler et al. (2018)[25] and Güneralp et al. (2017)[27] emphasize the significant potential of building code best practices for new constructions in the Global South and of large-scale building retrofitting in the Global North. Van Sluisved et al. (2016)[70] highlight the great potential of household energy-saving behaviours and lifestyle changes in achieving emission reduction objectives. Yet, whether the behavioural assumptions made in perspective studies can be reconciled with the behaviour of people we have been observing in historical data remains open for research. Studies looking at household historical investments in buildings characteristics are scattered (Auffhammer and Mansur, 2014)[7]. They focus on the role of dwelling characteristics and socio-economic variables

tioning penetration rate to estimate the AC saturation curve, taking account of income, price of both air conditioners and electricity as well. Air conditioning adoption is sensitive to both income and temperature, but the impact of the former driver is much larger.

[2]Davis and Gertler (2015)[14] study the relation between temperature, income and air conditioning adoption in Mexico. On the extensive margin, the authors find that annual CDD and income are strong determinants of the decision of adopting air conditioning.

(Gillingham et al. 2012[23]; Kriström and Krishnamurthy, 2014[40]; Ameli and Brandt, 2015[1]), while that of climate remains unexplored.

This paper examines the determinants of two adaptation responses aimed at ensuring the thermal comfort of households, AC and TI in eight OECD countries, including five European countries that traditionally have had relatively low AC and high TI adoption rates. We evaluate and compare the effect of climate conditions to a rich set of socio-economic and demographic factors, including income and attitudinal characteristics related to environmental policy. We next illustrate the implications of the observed behavioural choices for future residential AC and TI adoption around 2040 (2020-2060) under a set of plausible storylines regarding future climate change and selected socio-economic drivers.

The paper is divided into four sections. We first present the methodology, including the theoretical set-up, the empirical model, and the approach used to develop future projections. Then, we discuss the empirical results and future scenarios. A discussion and conclusion section contextualizes our results in relation to the existing literature and derives some policy implications.

2 Materials and Methods

2.1 A model for air conditioning and thermal comfort adoption

We model the discrete choice of thermal comfort technologies and behaviours, Air Conditioning and Thermal Insulation, following a basic utility framework as in McFadden (1973[43], 1981[44], 1984[45]). Specifically, for any household i a random utility model is applied as follows:

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

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

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.

In order to invest in thermal comfort, household i may choose whether to install air conditioning, AC_i, or thermal insulation, TI_i. For any household i we can assume that the marginal utility with respect to consumption is strictly positive and 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 maximization problem, in this framework the dependent variable is modeled as a latent variable:

$$tc^*_{ij} = \mathbf{x}'_{ij}\beta + \epsilon_{ij} \tag{2}$$

where tc^*_{ij} is the latent dependent variable reflecting the preferences of household i in the thermal confort technology $j \in \{AC, TI\}$. $\mathbf{x}_{ij}$ is a vector of regressors for each thermal comfort technology and includes attribute variables and characteristic variables. Attribute variables describe the external conditions affecting the choice (e.g. Cooling Degree Days, CDDs, and Heating Degree Days, HDDs). Characteristic variables 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 organization 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:

$$tc_{ij} = \begin{cases} 1 & \text{if } tc^*_{ij} > 0 \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

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 $tc_{ij} = 0$.

2.2 Empirical approach and data

The adoption equations Eq. (3) are estimated with a probit model for each technology, air conditioning and thermal insulation, using univariate probit regressions[3]. Our historical data come from the 2011 Environmental Policy and Individual Behaviour Change (EPIC)[4] survey conducted by the Organisation for Economic Co-operation and Development (OECD) in eleven countries (Australia, Canada, Chile, France, Israel, Japan, Korea, Netherlands, Spain, Sweden and Switzerland). We exploit the cross-household variation and match the energy-related and socio-economic information of the survey with climate data by focusing on the eight countries where households have been geocoded, Australia, Canada, France, Japan, Netherlands, Spain, Sweden and Switzerland[5].

Our variables of interest, AC and TI, refer to whether a household has an air conditioner[6] and whether a household has installed thermal insulation of walls and roof[7]. As framed in the questionnaire, the variable TI does not refer to the thermal mass of buildings nor to characteristics such as reflectivity, which can be characteristics related to different architectural practices that vary across countries. Country-fixed effects are absorbed by the country-fixed effects included in the empirical model, see Section 3.2.

Our climatic variables are long-term annual average Cooling (CDDs) and Heating (HDDs) Degree Days, measuring typical intensity and duration of hot and cold climate, commonly used as covariates in the energy demand literature. HDDs and CDDs have been calculated

[3]We tested the hypothesis of a joint decision of adopting both thermal comfort technologies using a bivariate probit model, but we reject such hypothesis. Despite the negative relationship between adopting air conditioning and installing thermal insulation, the bivariate probit outcomes do not differ from the results of the singular univariate probit regressions. The Wald test cannot reject the null hypothesis for which correlation coefficient is zero, $\rho = 0$.

[4]For more details, we recommend OECD (2014)[55]

[5]All non-geocoded households are dropped. 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. The dataset has been published a few years ago, and numerous studies have been published (e.g Kriström and Krishnamurthy, 2014[40]; Ameli and Brandt, 2015[1]; Dato, 2017[13]), therefore we do not discuss the details of the survey further. This study is the first to exploit the geocoded information to examine the role of climate conditions.

[6]The questionnaire asks for the number of AC, but we focused on the binary choice, yes if the number of AC is greater or equal than one, no, if zero.

[7]Possible answers were 1) Yes, 2) No, 3) Already equipped, 4) Not possible. We have coded (1) and (4) as yes, (2) and 4) as no.

using the daily temperature (°C) data computed from the 3-hourly global surface gridded temperature (0.25° x 0.25° resolution, approximately 27 km x 27 km) fields obtained from the Global Land Data Assimilation System (GLDAS, Rodell et al., 2004)[61], for the years 1986-2011. For each grid-cell the CDDs/HDDs are calculated using the American Society of Heating, Refrigerating and Air-Conditioning (ASHRAE) method (ASHRAE, 2009[4]), and fixing 18.3 °C as temperature baseline. This is the most used temperature threshold in the literature. We use this threshold being our countries located in temperate regions. CDDs computed using average daily temperature only consider the effect of dry-bulb temperature. In regions with high relative humidity such as the coastal regions in New South Wales (Australia), Ontario (Canada), and Southern Sweden CDDs can have limited applications in determining energy requirements for space cooling (Guan, 2008). For such regions, a variant of CDD accounting for humidity, called CDD wet-bulb, is recommended as a more suitable indicator than the conventional dry-bulb derived CDD (Guan, 2008[26]; Krese et al., 2012[38]). As a robustness test, in Section 3.2 we test our results to this definition of CDDs [8].

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. We use the latitude and longitude information provided in the EPIC survey to merge households with the resulting HDDs and CDDs.

2.3 Projections

In order to project how the adoption of AC and TI could evolve in the future, we combine the estimated marginal effects of statistically significant drivers with socio-economic and climate projections around 2040 (long-term average between 2020-2060), see section 3.3 for a detailed description of the scenarios used. The marginal effects are evaluated at the

[8] The methodology to compute CDD wet-bulb varies only in the use of wet bulb temperature instead of dry-bulb temperature. The base temperatures and the units also remain unchanged, thus making CDD wet-bulb easily comparable to CDD . The wet-bulb temperature is the minimum temperature to which air can be cooled by evaporative cooling, and, as such, contains information about air temperature as well as moisture content. For furthe,r details, readers are referred to Stull (2011a[67], 2011b[68]).

mean value of all covariates (Greene, 2003[24]):

$$\frac{\partial P(tc_{ij}=1|\mathbf{x}_{ij})}{\partial x_{ijk}} = \phi(\mathbf{x}'_{ij}\beta)\beta_k \tag{4}$$

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 standardized normal distribution. In the case of a dummy variable (e.g. home type, living in an urban area) the marginal effects are calculated as follows (Greene, 2003[24]):

$$P((tc_{ij}=1|\mathbf{x}_{ij}), d=1) - P((tc_{ij}=1|\mathbf{x}_{ij}), d=0) \tag{5}$$

We then compute future adoption rates for AC and TI in region r, tcs_{rj}^{Future} with $j = \{ac, ti\}$, for all households $i \in r$, by multiplying the historical regional shares, $tcs_{rj}^{History}$, with the percentage change induced by the relevant climatic and socio-economic drivers, x_{rjk}:

$$tcs_{rj}^{Future} = tcs_{rj}^{History}\frac{\partial tcs_{rj}}{\partial x_{rjk}} \tag{6}$$

The percentage change in the shares of AC and TI, tcs_{rj}, is obtained by multiplying the estimated marginal effects from Eqs. 4 and 5 with the percentage change in the driver of interest, x_{rjk}. In the case of a continuous variable, this reads as follows:

$$\frac{\partial tcs_{rj}}{\partial x_{rjk}} = \phi(\mathbf{x}'_{ij}\hat{\beta})\hat{\beta}_k(\frac{x_{rjk}^{Future}}{x_{rjk}^{History}} - 1) \tag{7}$$

Following this calculation, regional adoption shares change proportionally to the change in the probability of adoption. The impact of a dummy variable, such as living in an urban area, shifts the entire relationship between adoption and all other covariates, ceteris paribus, and therefore it is implemented as a shifting factor equal to the marginal effect described in Eq. 5.

3 Results

3.1 Households characteristics and climatic patterns in selected OECD countries

The variables used in our analysis are summarized in Table A.1. They include HDDs and CDDs, socio-economic characteristics of households such as occupation, socio-economic status, income and dwelling characteristics, demographics such as household head's sex and age, attitudinal characteristics summarizing the pro-environmental and energy-saving attitude of a household.

Figure 1 displays CDD and HDD maps for the eight EPIC countries included in the analysis, along with the distribution of households marked by the black points. Countries with the highest AC diffusion (Japan, Australia, Spain) are also the ones with the highest long-term (1986-2011) average CDDs, 703, 590 and 569, respectively. The reverse is true as well, less exposed to hot climate countries have lower adoption rates of air conditioning. About 43% of the households in the EPIC sample has implemented thermal insulation, with Australia and Netherlands leading (55% and 56%, respectively). Contrary to air conditioning adoption, there is no evidence of a clear pattern between thermal insulation and the climate variables, as also shown in the correlation plots in Figure A.1.

Table 1 also compares the mean and Standard Deviation (SD) values of CDDs with those of CDDs wet-bulb, along with all other variables. For a given dry-bulb temperature and surface-level air pressure (at relative humidity $<100\%$), the wet-bulb temperature is always lower than the dry-bulb temperature. The aggregated annual CDDs derived using wet-bulb temperature are therefore always lower than the corresponding standard CDDs in our sample. Degree-days (HDDs and CDDs) are most commonly used to explain heating and cooling needs [4]. Figure A.2 shows that this climatic indicator strongly correlates with the frequency of annual Heatwave Number based on Excess Heat Factor (HWN-EHF)[9]. HWN-EHF essentially measures the frequency of excess heat and heat stress (see Figure A.3 for mean values in the eight OECD countries), two attributes widely associated with human mortality and morbidity (Perkins et al, 2012[57]; Nairn and

[9] The HWN-EHF index also based on GLDAS data at the same 0.25° x 0.25° resolution was accessed from the recently published dataset of climate extreme indices [51], [50].

Fawcett, 2013[52])[10]. The strong correlation between CDDs and HWN-EHF in proximity of the locations of households suggest that long-term cross sectional variation in CDDs well approximates long-term exposure to the risk of heat waves.

Average household yearly income is reported equal to 41,734€. Income is a key driver of thermal comfort technology adoption (e.g. Ameli and Brandt, 2015[1]; Kriström and Krishnamurthy, 2014[40]; Krishnamurthy and Kriström, 2015[39]; Dato, 2017[13]), but when using survey data income is self-reported, and therefore likely to be measured with error. Moreover, annual income is subject to short-run shocks (e.g. a household head might lose its job during the year) and households are reluctant to declare their income. Indeed only a subset of households reports this information. We therefore build another measures of the Socio-Economic Status (SES) of each household, a wealth index following Filmer and Pritchett (2001)[21]. 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[72]). We use 17 variables in a binary or continuous form. In the wealth index, each asset is weighted by its factor score or weight, as shown in Table A.2. A household which owns a car and a big detached house furnished with more electric appliances would reach a higher SES. The wealth index we obtain results to be a good proxy of the income variable, and the correlation with income is almost 0.7. Being an asset-based index, countries that rank higher in terms of wealth (e.g. Canada) are not necessarily the countries with the highest income.

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%). It is important to clarify that our urbanization variable captures whether people lives in major town or cities and suburban areas, and therefore tends to underestimate urbanization rates. For example, in France, urbanization rate in our dataset is 47%, much lower than World Bank estimates, of about 79%[11]. Observing the rates about primary

[10] For a comprehensive discussion and formulation of HWN- EHF, readers are referred to Nairn and Fawcett (2013[52], 2014[53]).

[11] We are not able to separate small towns – which could fall under urban - from villages which could fall under rural, because in the survey they are reported under the same question. The questionnaire reports: How would you best describe the area in which you live? 1) Major town/city, 2) Suburban

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 of those living in a detached house. 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% ownership rate).

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. 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%).

Variables describing the attitudinal characteristics of households include three indices. With an interval between -2 and 2 the environmental attitude index summarizes household's attitude with respect to environment, for example, whether households are willing to change their lifestyle for the environmental sake or whether they believe in technological progress to deal with environmental issues[12]. The environmental concern index summarizes household's concerns 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, the higher the score, the higher the concern is. The energy behaviour index summarizes the energy-saving behaviours of a household with 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. The average index value for the our sample is equal to 7. Spain has the highest score, followed by France and Australia. Instead, the lowest scores is reported in Sweden. The dataset also reports whether a household is a member in an environmental NGO or not. The average commitment is around 10%, with Switzerland

(fringes of a major town/city), 3) Small town or village, 4) Isolated dwelling (not in a town or village). We grouped (1) and (2) under urban, (3) and (4) under rural.

[12]This index is constructed as the simple mean of a statement of agreement with seven propositions ranked between -2 and +2, strong agreement/disagrement, depending on how the question is framed.

and Japan reporting respectively the highest (22.8%) and the lowest (2.3%) rates.

Table 1: 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)
Mean CDD wet-bulb (1986-2011)	186.428	42.264	29.886	512.620	4.324	112.236	0.598	14.270	85.949
	(279.713)	(34.346)	(30.757)	(192.088)	(2.694)	(108.002)	(0.378)	(12.438)	(175.613)
Socio-economic characteristics									
Wealth index	6.62e-09	0.001	9.32e-09	9.67e-09	2.58e-08	2.18e-08	2.78e-08	1.14e-09	1.60e-04
	(0.830)	(0.964)	(0.907)	(0.820)	(0.845)	(0.853)	(0.996)	(1.000)	(0.898)
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)[a]	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

[a] Urban area is defined as a major town or city and its fringes.

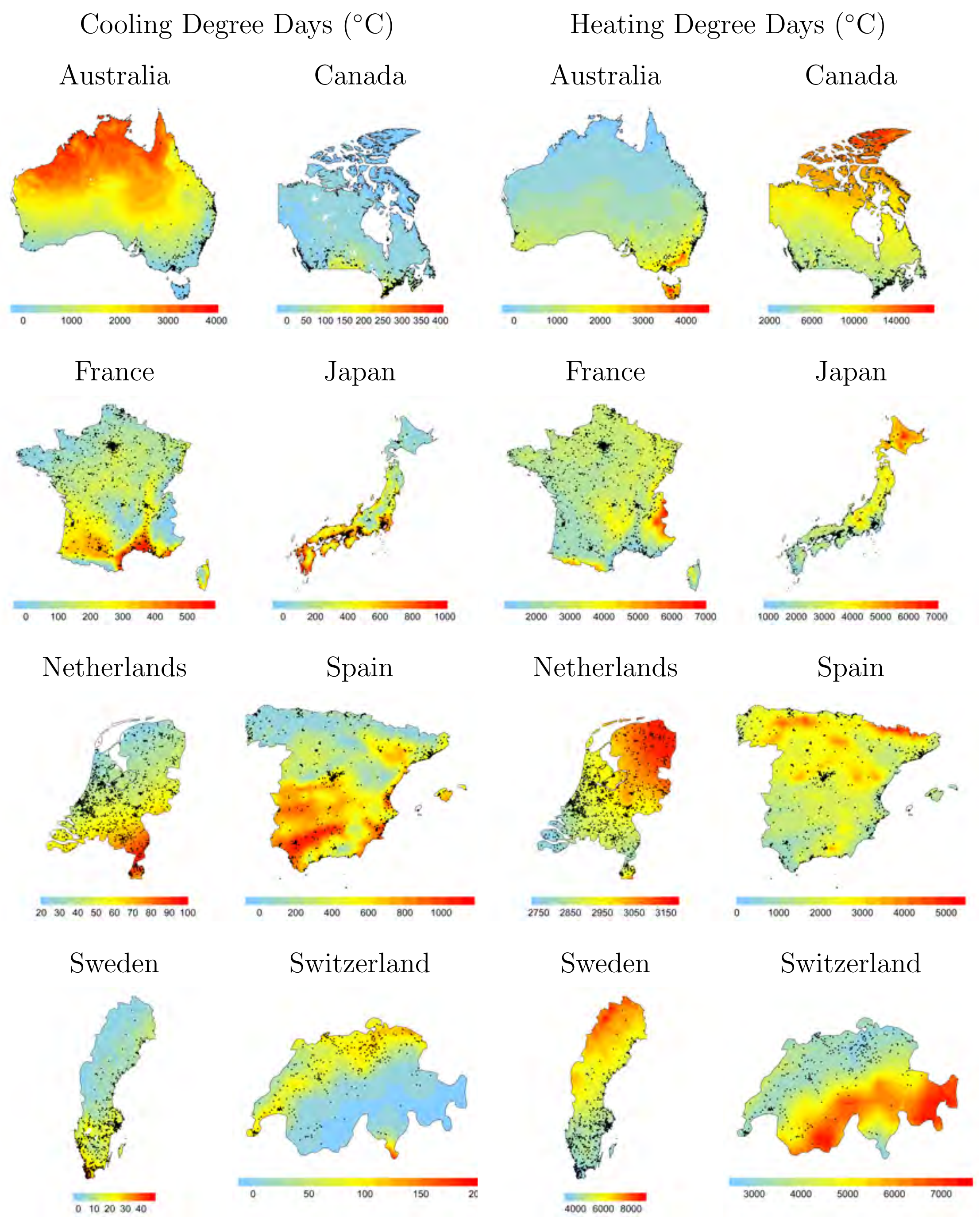

Figure 1: Cooling and Heating Degree Days computed at a base temperature of 18.3°C. Long-term average 1986-2011. Black circles overlaid on maps indicate geo-locations of households. Source: Authors' calculations based on GLDAS (Rodell et al., 2004)[61].

3.2 Determinants of AC and TI adoption. Evidence from historical data

Table 2 reports the estimated marginal effects of the variables described in the previous section on the probability of adopting AC and TI using the full sample (eight countries) as well as the European countries. It also compares the results obtained using the two indicators of socio-economic status, the wealth index and income[13].

Climate variables mostly influence the choice of adopting AC in a non-linear way, whereas evidence of an impact on TI is found only in European countries. Households in hotter places in Europe have a lower probability of improving walls and roof insulation, but the effect is reversed when the number of CDDs and HDDs is sufficiently large. Exposure to a warmer climate raises the probability that a household adopts air conditioning. The linear term of CDDs is strongly and positively related to the technology decision in both regressions, as found in previous contributions (e.g. Sailor and Pavlova, 2003[64]; Biddle, 2008[9]; Rapson, 2014[59]; Davis and Gertler, 2015[14]). The squared CDD term is negative, pointing at the effect of saturation, while the interaction term between CDDs and HDDs is positive, suggesting the presence of acclimatization effects as in Biddle (2008). An increase in CDDs has a larger impact on households living in colder countries (with a higher average number of HDDs) because people are less used to hot climate, and therefore have a lower temperature balance point. Overall, a 1% increase in CDDs raises the probability of adopting air conditioning by 0.11%, assuming HDDs take the mean value of 2726 degree days. This might appear as 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 an increase in the adoption probability of 11%. Using CDDs wet-bulb as opposed to CDDs computed using dry-bulb temperature leads to a larger marginal effect on both AC and TI adoption, and this effect is always mitigated or amplified by average HDDs. Overall, a 1% increase in CDDs wet-bulb raises the probability of adopting air conditioning by 0.27%, see Table A.4. At the same time, if countries are not inclined to AC, as in Europe, this interaction term can have a negative sign, as indeed observed for the European sub-sample. A negative sign on the interaction variables can also be capturing accustomization to AC in less warmer countries.

[13] Marginal effects are estimated at the sample mean. The estimated coefficients are available upon request. All regressions include robust standard errors and country-specific fixed effects.

Socio-economic characteristics, in particular income, wealth, home tenure and ownership are all important determinants of both air conditioning and thermal insulation, in line with existing studies (Biddle, 2008[9]; Rapson, 2014[59]; McNeil and Letschert, 2008[46]; Davis and Gertler, 2015[14], Gillingham et al., 2012[23]; Ameli and Brandt, 2015[1]), with the marginal effect being larger for the latter type of investment. An increase in the wealth index 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 goes up by 28.6%. The impact of wealth is also much larger compared to that of income, as a one-standard-deviation increase in income raises the probability of adopting the two thermal comfort technologies by 1.8% (AC) and 2.5% (TI), see Table A.3. Standardized regressions also highlight the much larger impact of climatic conditions compared to socio-economic ones, especially income, with a standard deviation increase in CDD raising the the probability of adoption by 13% plus an additional component that depends on mean HDD conditions.

Our estimates support the existence of a strong correlation between air conditioning and urbanization. Note that the marginal impact might be overestimated due to the definition of urbanization, see Section 3.1. We observe that living in a major city or town significantly increases the probability of adopting air conditioning. As a household moves its primary residence from a rural area to an urban area, the probability of adopting air conditioning increases by about 6%. For thermal insulation we report an opposite effect, which might be due to the institutional and social constraints arising more frequently when living in an urban context.

Demographic characteristics also affect technology decision. Air conditioning adoption appears as an adaptation strategy households use to protect minors from the risk posed by exposure to hot climate more than thermal insulation[14]. A one-standard-deviation (22.1%) increase in the share of minors raises the probability of adopting air conditioning by about 3% (see Table A.3). 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

[14]Deschênes and Greenstone (2011)[17] 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. The non-significance for thermal insulation of the share of minors is in line with Gillingham et al. (2012)[23] findings.

insulation.

Attitudes towards the environment also influence adaptation choices with significant energy implications. Energy conservation-oriented consumers are indeed less likely to buy new air conditioners whereas they are more inclinded to rely on thermal insulation. While an environmentally-friendly attitude negatively affects the probability of adopting air conditioning, installing thermal insulation is positively influenced by environmental concerns.

Table 2: Univariate probit regressions for Air Conditioning and Thermal Insulation in the full sample and EU countries using the wealth index and income.

Variable	Full sample				EU sample			
	Air Conditioning		Thermal Insulation		Air Conditioning		Thermal Insulation	
	Wealth index (Sd. error)	Income (Sd. error)	Wealth index (Sd. error)	Income (Sd. error)	Wealth index (Sd. error)	Income (Sd. error)	Wealth index (Sd. error)	Income (Sd. error)
Climate								
Mean HDD (1986-2011)	2.68e-05*	2.07e-05	2.28e-06	3.36e-06	7.05e-06	-3.29e-06	-2.85e-05	-3.62e-05
	(1.55e-05)	(1.64e-05)	(1.54e-05)	(1.61e-05)	(2.09e-05)	(2.25e-05)	(2.38e-05)	(2.62e-05)
Mean CDD (1986-2011)	4.95e-04***	4.12e-04***	-1.18e-04	-1.47e-04	0.0010***	9.25e-04***	-8.64e-04**	-0.0010***
	(1.04e-04)	(1.10e-04)	(1.06e-04)	(1.10e-04)	(2.59e-04)	(2.88e-04)	(3.55e-04)	(3.74e-04)
CDD squared	-1.17e-07**	-8.81e-08	-1.77e-09	8.01e-09	-2.54e-07	-2.19e-07	4.30e-07*	4.99e-07**
	(5.07e-08)	(5.41e-08)	(5.22e-08)	(5.41e-08)	(1.72e-07)	(1.92e-07)	(2.37e-07)	(2.49e-07)
CDD x HDD	2.58e-07***	2.57e-07***	5.24e-08	4.31e-08	-1.81e-07**	-1.76e-07**	3.50e-07***	3.61e-07***
	(4.36e-08)	(4.65e-08)	(4.40e-08)	(4.53e-08)	(7.74e-08)	(8.61e-08)	(1.12e-07)	(1.17e-07)
Socio-economic charact.								
Wealth index	0.114***		0.286***		0.107***		0.294***	
	(0.0105)		(0.0108)		(0.00953)		(0.0133)	
Income		7.52e-07*		1.07e-06***		1.22e-06***		9.23e-07
		(3.96e-07)		(3.64e-07)		(4.52e-07)		(5.67e-07)
Urban area (Yes = 1)[a]	0.0592***	0.0582***	-0.0149	-0.0283*	0.0377***	0.0350**	-0.0175	-0.0333*
	(0.0147)	(0.0165)	(0.0147)	(0.0157)	(0.0132)	(0.0155)	(0.0177)	(0.0193)
Home size (m^2)		1.04e-04		7.43e-04***		2.48e-04		0.0010***
		(1.40e-04)		(1.33e-04)		(1.64e-04)		(2.15e-04)
Home tenure	0.0016***	0.0021***	-0.0017***	-0.0019***	0.0015***	0.0019***	-0.0019***	-0.0021***
	(5.68e-04)	(6.51e-04)	(5.49e-04)	(6.01e-04)	(5.12e-04)	(6.13e-04)	(6.70e-04)	(7.52e-04)
Home owner (Yes = 1)	0.0133	0.0761***	0.0827***	0.224***	0.0137	0.0558***	0.0555***	0.186***
	(0.0174)	(0.0177)	(0.0165)	(0.0157)	(0.0161)	(0.0169)	(0.0206)	(0.0206)
Home type (Apt. = 1)	0.0572***	-0.0112	0.0282	-0.118***	0.0560***	-0.00817	0.0568**	-0.102***
	(0.0194)	(0.0203)	(0.0183)	(0.0184)	(0.0179)	(0.0195)	(0.0222)	(0.0234)
Demographics								
Age	-7.34e-04	-8.29e-04	0.0028***	0.0023***	-9.77e-04*	-0.0011*	0.0016**	0.0011
	(5.56e-04)	(6.27e-04)	(5.48e-04)	(5.86e-04)	(5.17e-04)	(6.15e-04)	(6.75e-04)	(7.44e-04)
Household size	-0.0178**	0.00240	-0.0426***	0.000354	-0.0213***	-0.00568	-0.0382***	0.00167
	(0.0078)	(0.0087)	(0.0075)	(0.0080)	(0.0078)	(0.00897)	(0.0101)	(0.0112)
Share of under 18	0.141***	0.140***	0.0605	0.0143	0.108***	0.131***	0.0351	4.63e-04
	(0.0407)	(0.0457)	(0.0393)	(0.0430)	(0.0378)	(0.0437)	(0.0492)	(0.0550)
Gender (Male = 1)	0.0193	0.0426***	0.0231	0.0392***	-0.0036	0.0200	0.0281	0.0427**
	(0.0144)	(0.0158)	(0.0141)	(0.0149)	(0.0132)	(0.0151)	(0.0171)	(0.0186)
Attitudinal charact.								
Envt. Attitude Index	-0.0498***	-0.0509***	-0.0094	-0.0237*	-0.0446***	-0.0499***	-0.0169	-0.0309**
	(0.0120)	(0.0133)	(0.0118)	(0.0125)	(0.0110)	(0.0128)	(0.0147)	(0.0157)
Energy Behav. Index	-0.0184***	-0.0157***	0.0299***	0.0263***	-0.0135***	-0.0126***	0.0367***	0.0296***
	(0.0041)	(0.0046)	(0.0040)	(0.0043)	(0.00395)	(0.0046)	(0.0051)	(0.0056)
Envt. Concern Index	0.00175	0.0014	0.00899*	0.0083	4.37e-04	3.06e-04	0.0107*	0.00952
	(0.00497)	(0.0055)	(0.0048)	(0.0052)	(0.0047)	(0.0054)	(0.0061)	(0.0067)
Member Envt. NGO (Yes = 1)	0.0221	0.0363	0.0271	0.0530**	0.0217	0.0383	0.0225	0.0411
	(0.0234)	(0.0256)	(0.0232)	(0.0241)	(0.0218)	(0.0252)	(0.0274)	(0.0286)
Other								
Country fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6780	5638	6780	5638	4436	3523	4436	3523

[a] Urban area is defined as a major town or city and its fringes.
[b] Marginal effects at means of the dependent variable with robust standard error in parentheses.
[c] *, ** and *** indicate p-value at 0.1, 0.05 and 0.01 significance level respectively
[d] We have also included (but not above-reported) occupation and years of education

3.3 Future projections of AC and TI adoption

Long-term average AC and TI ownership around 2040 (mean between 2020 and 2060) are projected by combining our empirical estimates from Table 2 with the socio-economic and climate scenarios developed within the new scenario framework described in van Vuuren et al. (2012 [71]). General equilibrium adjustments induced by changes in electricity and appliance prices are not taken into account at this stage.

We consider the two temperature increase scenarios Representative Concentration Pathways (RCPs) RCP4.5 and RCP8.5 associated with a warming effect of about +2°C in 2040 and of about 2.5 and 4.5°C in 2100, respectively. Future temperature scenarios are from the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP), which provides bias-corrected daily maximum and minimum temperatures on a 0.25°x0.25° grid up to 2100 period for the RCP4.5 and RCP8.5 simulated by 21 Earth System models participating in the global Climate Model Intercomparison Project round 5 (CMIP5). We used the multi-model median across the 21 climate models and compute the long-term change in CDDs and HDDs in 2040 as mean over the period 2021 and 2060[15]. The historical reference period is computed from the same database as long-term average between 1986 and 2005. The socio-economic scenarios (Shared-Socio economic Pathways, SSPs) describe five plausible and internally consistent storylines of how socio-economic variables might unfold over the century (O'Neill et al. 2017[56]). Table 3 recalls the main assumptions regarding the evolution of GDP and the share of minors, and Figure A.4 and Table A.6 report the absolute and percentage changes in all drivers used in the projections, including CDDs and HDDs. Growth rates between 2020 and 2060 have been computed from the SSP database[16]. The share of minors declines across all SSPs. Income growth is relatively moderate. It goes up by between 37% in SSP3 and 68% in SSP5. Our future projections consider urbanization as a shifting factor that does not vary across SSPs. In the sample of OECD countries considered in this study urbanization rates are already high. Future increases are moderate and do not vary much across SSPs. Urbanization patterns for Australia, Canada, France, Netherlands, and Sweden are not differentiated across SSPs. Around 2040, CDDs increase uniformly relative to the historical period

[15]Note that the NEX-GDDP database only provides temperature and precipitation, therefore our projections are based on the estimates obtained using CDDs and not CDDs wet-bulb.

[16]The SSP database is available at `https://tntcat.iiasa.ac.at/SspDb/`

1986-2005 across all 101 administrative units of our OECD countries with large spatial variation, especially in the RCP8.5 scenario[17]. The largest increases in CDDs relative to the observed standard deviation are found in Sweden, Switzerland, Netherlands Canada, and France. HDDs decline. Although absolute declines are larger compared to the increase in CDDs, the percentage variations are smaller, having these countries a temperate climate.

Table 3: Shared Socioeconomic Pathways. Summary of main elements as in O'Neill et al. (2017)[56].

	SSP1 Taking the green road	**SSP2** Middle of the road	**SSP3** Regional rivalry	**SSP4** Inequality	**SSP5** Fossil-fueled development
GDP	Medium/High income growth (26%)	Medium income growth (24%)	Slow economic growth (22%)	Medium-high in high-income countries (27%)	High income growth (30%)
Share of minors	Rapid demographic transition due to education and health investments leading to low fertility, low mortality (−10%)	Medium fertility, mortality, education, health investments lead to a medium decline (−8%)	Share of minors declines the most due low fertility and high mortality (−14%)	Share of minors declines the most due low fertility and high mortality (−14%)	Share of minors declines the least due to higher fertility rates (in some countries can increase) (−3%)

Note: The % figures indicate the mean percentage change in drivers between 2020 and 2060 relative to 2010 in the sample of selected OECD countries computed from the SSP database available at `https://tntcat.iiasa.ac.at/SspDb/`. See also Figure A.4.

Figure 2 shows the contribution of socio-economic and climatic drivers[18] to the future predicted regional shares of AC for the SSP5-RCP8.5 scenario (top panel). The lower panel shows the combined effect of all drivers across different SSPs and RCPs. How all drivers vary across all scenarios is illustrated in Figure A.5. Income and demographics characteristics play only a minor role compared to urbanization and changes in climatic conditions, which are the main drivers of future AC in most countries. The boxplots

[17]Note that large percentage changes occur when the base value is low, e.g. in Sweden. A percentage increase in CDDs by 1160%, the maximum increase estimated for Sweden, corresponds to an increment in Cooling Degree Days of 67, almost six time the historical standard deviation.

[18]In the graph we focus on CDDs, but actual calculation take into account the change in HDDs, which affects the marginal impact of CDDs.

display the geographic variation within countries, as projections have been developed at sub-national regional scale. Broadly, we can distinguish three groups of countries. Sweden and Canada, where climatic factors are the major drivers under both climate scenarios, shifting the entire distribution of AC adoption share (Figure 2, top panel), and leading to higher minimum and maximum values compared to urbanization (the min-max range in Canada shifts from 22-67% to 33-89% due to CDDs, and to 28-73% due to urbanization, in Sweden from 5-33% to 12-47% , and to 11-39%). In Switzerland, Australia, and the Netherlands the relative impact of CDDs and urbanization on the distribution of AC is comparable. In France and Spain, and to a lower extent in Japan, urbanization has a slighter larger impact, especially on the regions with an adoption rate below the median value, as urbanization almost doubles the minimum value of the adoption share, from 4% and 5% in 2011 to 9% and 11%, respectively. In Spain and France, CDDs lead to a slighlty larger maximum adoption share compared to urbanizaton.

In all countries the future distribution of AC adoption rates shifts upward (Figure 2, bottom panel) and exhibits increased variation, especially in colder countries under vigorous warming for the regions above the median AC share. Countries with large adoption rates in 2011 - Australia, Japan - do not show much variation in any dimension nor in the distribution. Climate change and urbanization in both countries will drive adoption to basically 100% across all regional subdivisions in Japan and in the upper quartile in Australia (up to 93%).

Figure 3 compares the results for TI and AC for the sub-set of European countries using the estimated coefficients relative to the EU sub-sample. Results on TI using the full sample estimates are shown in Figure A.8. Those results only include the impact of income and urbanization. Besides Sweden, which shows an increase in the TI share when climatic factors are also included, results for all other countries are in line with those in Figure 3.

Adoption rates of TI are much higher compared to AC, with the exception of Spain, with a mean value of about 30%. Climate change and income growth both go in the direction of fostering TI adoption, but the constraints set by urbanization prevail, leading to a reduction in the future adoption of TI. Exceptions are Sweden, where we observe the largest projected increase in CDDs, and Switzerland. We should note that our projections are based on the central estimated marginal effects, but each elasticity is also associated

with a margin of uncertainty, measured by the confidence interval. Moreover, for each country we provide two sets of estimates. The first ones based on the full sample. The second ones based on the EU and non-EU sample. Differences between these two sets of elasticities do not lead to significant differences in projected adoption, though those based on the EU-sample estimates are slightly smaller, as illustrated in Table A.5.[19]
Our empirical results also suggest that dedicated policies capable of increasing the attitude of people towards energy saving practices, leading to a higher score in the energy behaviour index, could also affect future adoption patterns. The energy behaviour index has a mean value of 7.32 and a standard deviation of 1.9, with 50% of households having a score between 6 and 9. If all households increase energy-saving behaviour to reach an index of 7, the share of TI could increase by 1.2%, on average, whereas that of AC share could fall by up to 4% (mean -0.63%). If all European households improved their behaviours to achieve the highest score of 10, the share of TI could increase from about 43% to 52%, whereas that of AC could fall from 24-25% to 21%, on average, under vigorous warming. Consider for example, SSP1 - taking the green road - the scenario of sustainability and greater environmental awareness. In Spain, for example, greater attention towards energy-saving habits could reduce the interquartile range of AC from 19-67% to 17-65%. In Sweden, from 18-23% to 12-17%.

[19]Only in the case of Sweden the weight of socio-economic drivers (income, share of minors, urbanization) and of climate (CDDs) slightly changes with the former drivers prevailing when full-sample estimates are used, and the latter being larger when the EU-sample elasticities are used.

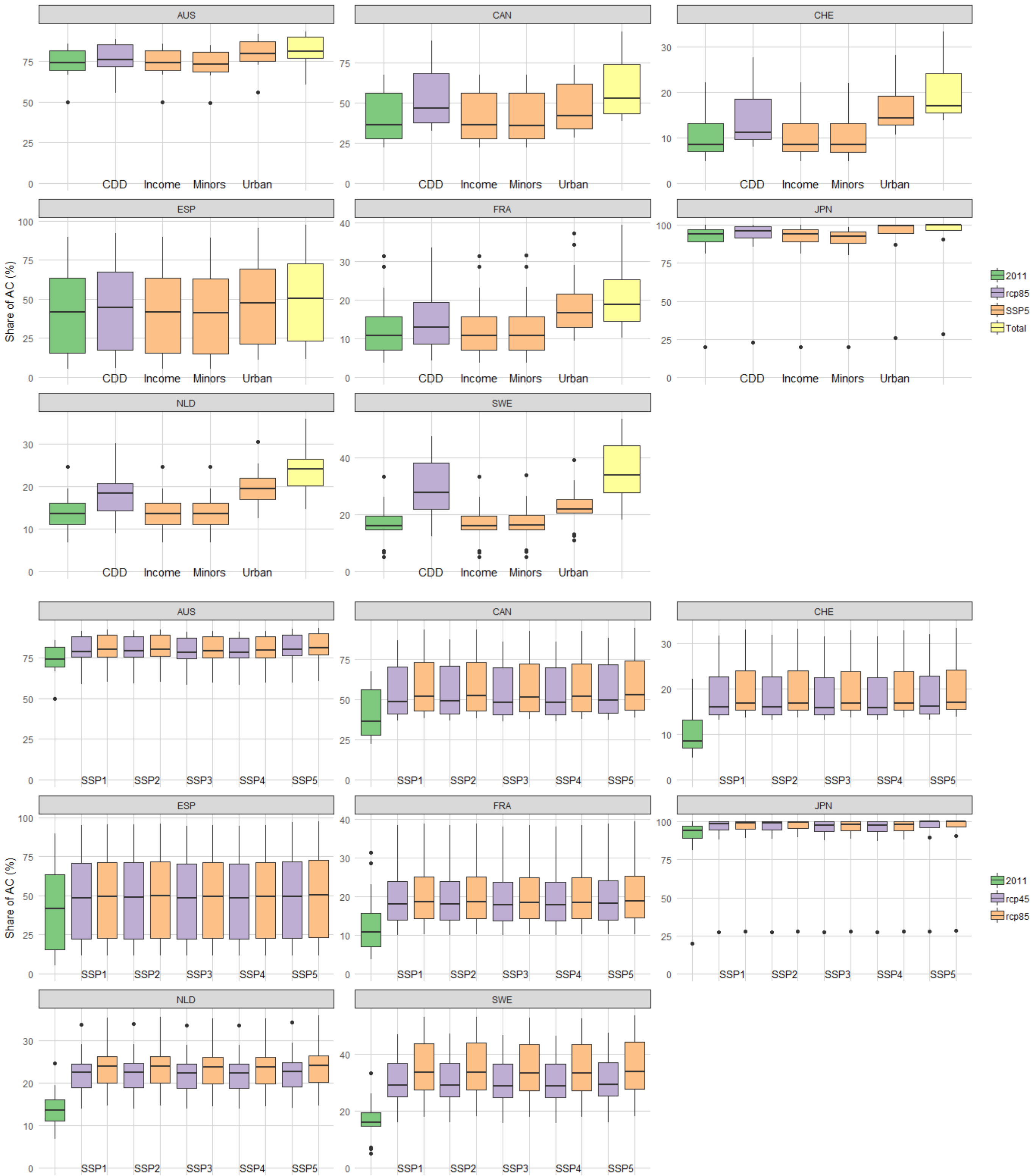

Figure 2: Projected (2020-2060) and current (2011) shares of Air Conditioning in SSP5-RCP8.5 (top panel) and across SSPs and RCPs (bottom panel). Full sample estimates from Table 2. Boxplots display within-country regional variation in adoption shares. The CDD component takes into acccount the interaction with HDDs.

Figure 3: Projected (2020-2060) and current (2011) shares of Air Conditioning and Thermal Insulation in SSP5-RCP8.5 (top panel) and across SSPs and RCPs (bottom panel). EU sample estimates from Table 2. Boxplots display within-country regional variation in adoption shares. The CDD component takes into acccount the interaction with HDDs.

4 Discussion and conclusion

This paper contributes to the understanding of households' decisions regarding thermal comfort behaviour through technology adoption. Empirical results based on historical data for a sample of households in OECD countries show that climatic factors (Cooling Degree Days, CDDs), urbanization, demographics (age, gender, share of minors) and household characteristics (ownership, tenure) are relatively more important than income. When combined with future socio-economic pathways and climate change scenarios, global warming and urbanization patterns, if not well-managed, can lock in future societies of temperate, industrialized countries into maladaptive responses such as Air Conditioning (AC). Especially in Southern and Central Europe, climatic and socio-economic factors work in favour of AC rather than Thermal Insulation (TI). For example, in Spain, the regional average AC adoption share of the upper quartile of the AC distribution would increase from 64-90% to 68-94%, in France from 16-31% to 21-26%, depending on the scenario. The share of French regions reaching 20% adoption rates will increase from about 15 to 25%. The maximum adoption share will increase from 33 to 39% in Sweden, from 25 to 30% in the Netherlands, from 22 to 27% in Switzerland. In Japan all regions in the top percentile of the distribution will shift towards full adoption, although behavioural changes towards energy-saving behaviours can mitigate the impact of climate, income, and urbanization trends. In colder European countries, the increase and the reduction in hot and cold days, respectively, could foster TI. In Sweden, the majority of the regions represented by the interquartile range would shift from a TI adoption rate in the range of 29-40% to 30-50%, in Switzerland from 38-55 to 42-54%. The adoption share of the regions in the upper quartile would increase from 40-50% to 46-95%.

These emerging trends, even in countries in which AC ownership has been historically low, such as Europe, suggest that improving the energy efficiency performance of AC equipment as well as developing sustainable cooling technologies are items of high policy-relevance. High-efficiency AC units with efficiency rates higher than those of market averages are already available, but the Global Innovation Index 2018 suggests that key innovations related to cooling as well as breakthrough insulation materials are either not viable at current prices, or not even available (Dutta et al. 2018[18]). The role of ambitious policy packages combining regulatory measures, energy labelling, and market incentives will be crucial to address the increasing electricity demand for residential space cooling and avoid trade-offs between adaptation behaviours and mitigation objectives. This may pose a challange for European countries, where, despite well-established mitigation targets recently renewed in a specific package aimed at ensuring clean energy for all Europeans,[20] efforts towards the achievement of the EU 2020 energy efficiency goal are currently lagging behind, undermining the path to the more ambitious 2030 targets (EEA 2018[20]). A sectoral regulation directly addressing energy efficiency and renewable deployment in space heating and cooling is still at an early stage.[21] Moreover, whether efficiency improvements in AC could lead to rebound effects as found for other energy-saving technologies (Fouquet 2014[22]) remains to be studied.

Improving thermal insulation of buildings through the adoption of building codes, is among the most effective policy instruments for reducing residential energy consumption and reduce adaptation needs for cooling (Samuel et al. 2013[65]), but it has some limitations. Airtightness and internal bulky-insulation may induce overheating rather than cooling in dwellings (Taylor et al. 2016[69]), increasing health risks and energy demand for cooling. To be effective, thermal insulation should be installed choosing materials, thickness, and position according to construction settings (Bojic et al. 2001[10]; Wang and Fukuda, 2019[73]) and local climatic conditions (Aktacir et al. 2010[3]). Performance may increase if TI is efficiently combined with other passive cooling options, such as high-performance windows and shading (Mirrahimi et al. 2016[49]). Once adopted effectively, insulation generates both economic and environmental benefits, reducing initial and operating costs of AC (Aktacir et al. 2010[3]), as well as the energy consumption for cooling (Bojic et al. 2001[10]; Wang and Fukuda, 2019[73]).

Our empirical evidence showing that households concerned about energy efficiency or the environment are less inclined towards AC and more likely to adopt TI leads us to speculate that well-designed and communicated policies could have an impact on people. Especially in more urbanized contexts, improving the thermal performance of buildings needs to be addressed by dedicated policies dealing with split incentive barriers of renters and institutional and credit-constraints of owners. In Europe, for example, over 70% of the population is owner-occupier, but at the same time energy poverty is a growing problem

[20]the Clean Energy for All Europeans package that will be finalized in the first few months of 2019 includes a 2030 energy efficiency target of at least 32.5% and specific measures for the building sector.

[21]see the European Commission 's Communication for "An EU Heating and Cooling Strategy", COM(2016) 51 final.

(Bukarica et al. 2017[11]). Moreover, although new buildings on average consume about 40% less energy than old buildings, in Europe new dwellings represent only about 1% of the existing stock, pointing at the urgency of implementing effective additional policy measures (Rousselot 2018[63]). Given its multiple benefits in terms of reduced emissions, energy poverty, and improved energy security, numerous countries around the developed and developing world have plans to improve building codes in the context of the Nationally Determined Contributions under the Paris Agreement (NDCs, Davide et al. 2018[15]) to reduce climate change vulnerability as well as energy costs. If well-designed and properly enforced, they may represent a powerful tool, especially in emerging economies, where space cooling demand is projected to quickly go up in the near future.

From a methodological perspective we provide a new diffusion model for AC and TI that can inform projection-based studies and enrich future energy scenarios. How the demand for AC and TI is represented in climate-economy-energy models indeed is one of the gaps highlighted by recent studies on energy and cooling scenarios (Levesque et al 2018[41], Mastrucci et al. 2019[42]), as well as by the literature on low energy demand mitigation strategies (Grubler et al. 2018). Despite the richer characterization compared to the studies used as reference for the modelling of AC diffusion (e.g. Sailor and Pavlova, 2003[64], McNeil and Letschert, 2010[47]), our study is not without limitations. Data availability does not allow us to control neither for electricity prices nor for investment and installation costs, which previous studies suggest to matter. Biddle (2008)[9] analyzes the diffusion of AC in US from commercial and residential buildings, highlighting the role of real income, declines in electricity rates and in installation costs. Rapson (2014)[59] estimates a dynamic, infinite-horizon, discrete-choice optimization model for room and central air conditioners and show that, on the extensive margin side, unit efficiency, more than unit price, affects household choice of installing or replacing an air conditioner. Data on actual sales of air conditioners, their costs and efficiency would make it possible to study whether improved efficiency of AC could lead to rebound effects.

Concerning our adoption scenarios, they should be considered illustrative, as they only factor in a subest of determinants for which quantitative scenarios are available. Consider for example age, gender, and home ownership. Our empirical results in Table A.3 suggest that those characteristics have a strong impact on TI investments. Combined with the ageing population, those drivers could actually compensate the impact of urbanization. In our study, the impact of urbanization is implemented as a shifting factor that is constant across SSPs, but the urbanization process of SSP1 narrative is qualitatively different from that of SSP5. Finally, our study highlights the different effect of wealth compared to that of income, suggesting that wealth could have a much larger impact on adoption choices for both AC and TI. Lacking scenarios of how wealth will evolve in the future, we are not able to include that in the projections.

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A Further results

Table A.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)
Mean CDD wet-bulb (1986-2011)	Continuous	Mean cooling degree days computed with wet-bulb temperature (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

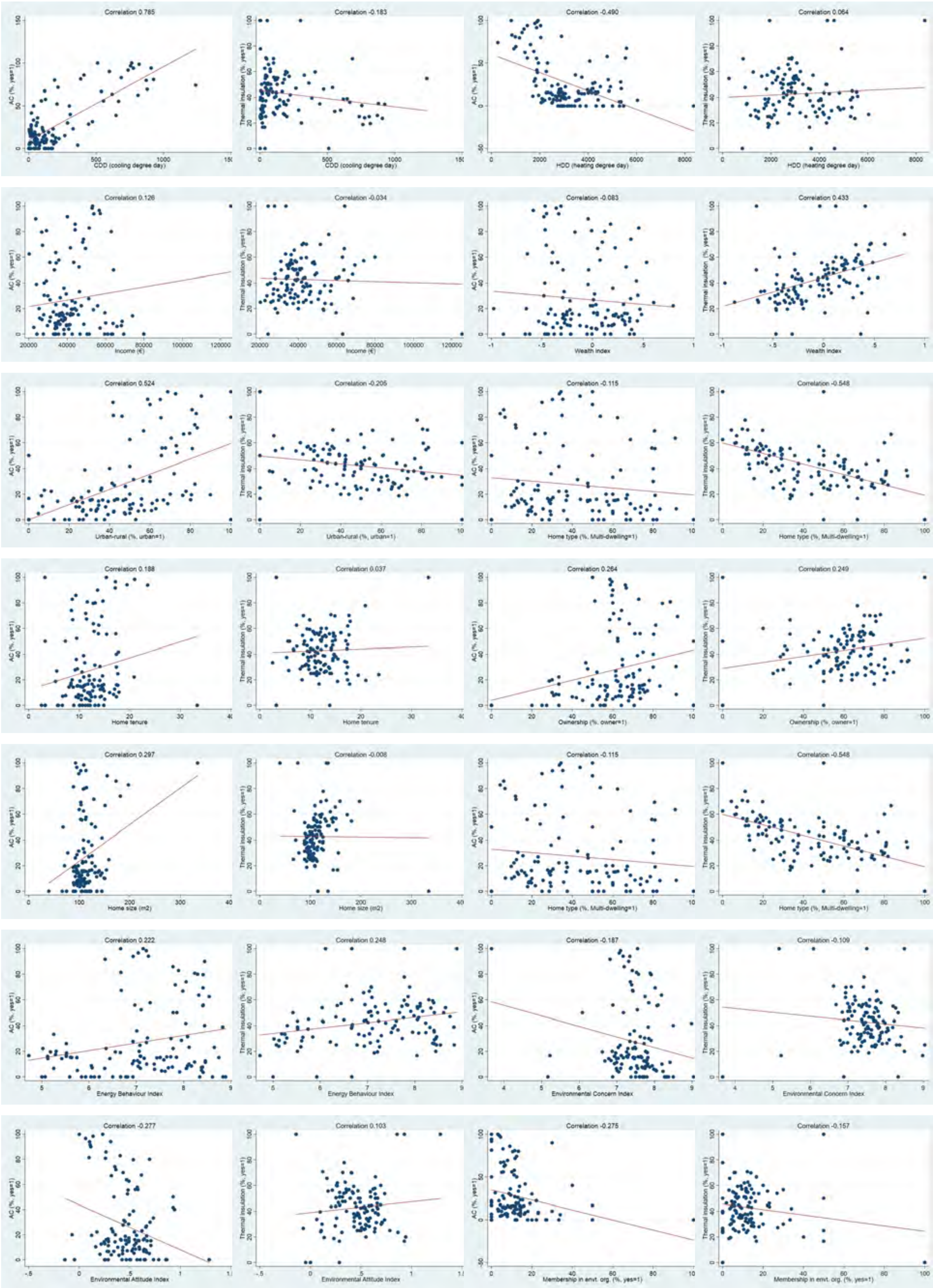

Figure A.1: Correlation plots.

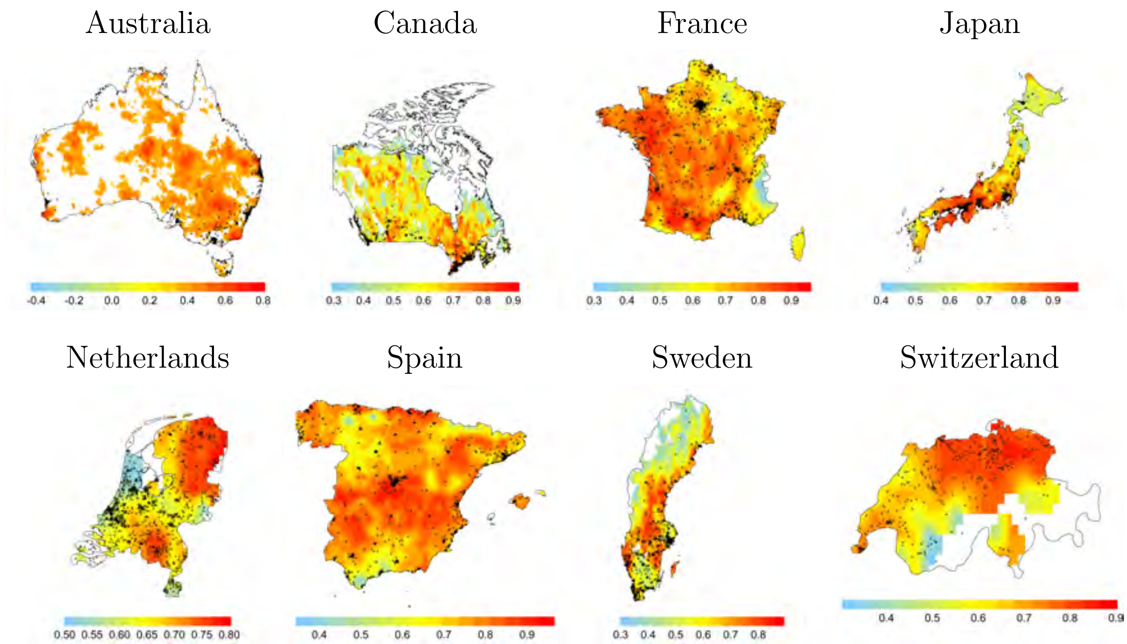

Figure A.2: Correlations between CDDs and the Heatwave Number based on Excess Heat Factor (HWN-ECF) at 90% significance level, computed at each grid-cell, 1986-2011. Black circles overlaid on maps indicate geo-locations of households used in our study. White regions indicate correlations either not computed or correlations were insignificant. The correlations were computed using R package raster (Hijmans, 2019).

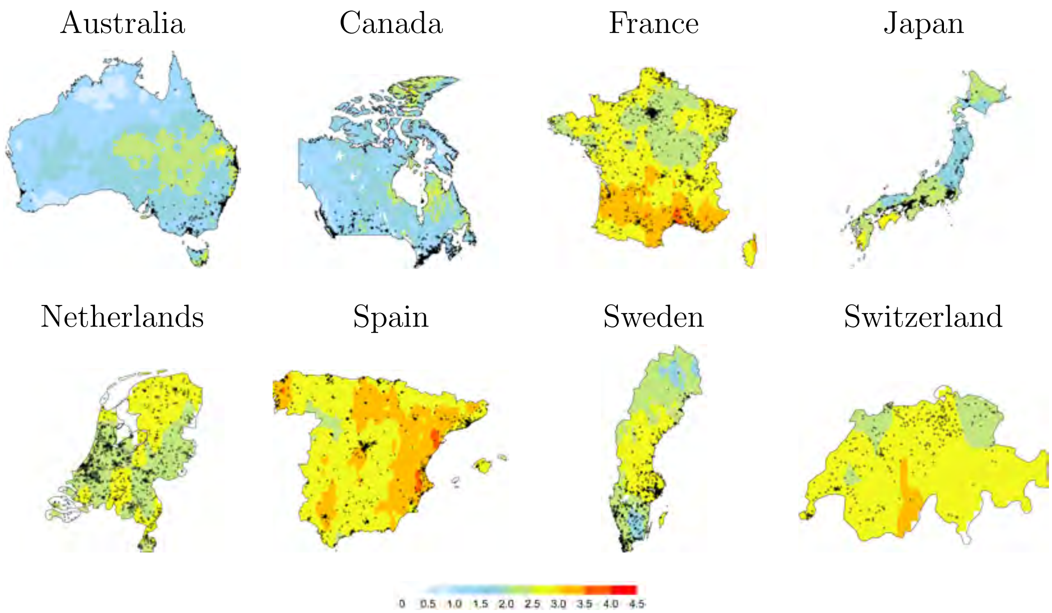

Figure A.3: Mean of 1986-2011 Heatwave Number based on Excess Heat Factor (HWN-EHF). Black circles overlaid on maps indicate geo-locations of households.

Table A.2: Principal Component Analysis 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

Table A.3: Standardised univariate probit regression results for full sample and EU sample. Air Conditioning and Thermal Insulation. Income.

Variable	Full sample		EU sample	
	Air Conditioning	Thermal Insulation	Air Conditioning	Thermal Insulation
	(Sd. error)	(Sd. error)	(Sd. error)	(Sd. error)
Climate				
Mean HDD (1986-2011)	0.0271	0.00438	-0.00326	-0.0359
	(0.0214)	(0.0210)	(0.0223)	(0.0260)
Mean CDD (1986-2011)	0.136***	-0.0486	0.247***	-0.273***
	(0.0364)	(0.0363)	(0.0768)	(0.0997)
CDD squared	-0.0378	0.00344	-0.0535	0.122**
	(0.0232)	(0.0232)	(0.0472)	(0.0610)
CDD x HDD	0.103***	0.0173	-0.0592**	0.122***
	(0.0186)	(0.0182)	(0.0290)	(0.0393)
Socio-economic charact.				
Income	0.0179*	0.0253***	0.0250***	0.0189
	(0.00939)	(0.00864)	(0.00930)	(0.0116)
Urban area (Yes = 1)	0.0582***	-0.0283*	0.0350**	-0.0333*
	(0.0165)	(0.0157)	(0.0155)	(0.0193)
Home size (m^2)	0.00656	0.0471***	0.0129	0.0540***
	(0.00887)	(0.00842)	(0.00854)	(0.0112)
Home tenure	0.0277***	-0.0252***	0.0249***	-0.0282***
	(0.00866)	(0.00800)	(0.00818)	(0.0100)
Home owner (Yes = 1)	0.0762***	0.224***	0.0558***	0.186***
	(0.0177)	(0.0157)	(0.0169)	(0.0206)
Home type (Apt. = 1)	-0.0113	-0.118***	-0.00817	-0.102***
	(0.0203)	(0.0184)	(0.0195)	(0.0233)
Demographics				
Age	-0.0112	0.0309***	-0.0154*	0.0155
	(0.00848)	(0.00793)	(0.00834)	(0.0101)
Household size	0.00312	0.000452	-0.00681	0.00200
	(0.0111)	(0.0102)	(0.0107)	(0.0134)
Share of under 18	0.0311***	0.00319	0.0299***	0.000106
	(0.0102)	(0.00958)	(0.00996)	(0.0125)
Gender (Male = 1)	0.0427***	0.0392***	0.0200	0.0427**
	(0.0158)	(0.0149)	(0.0151)	(0.0186)
Attitudinal charact.				
Envt. Attitude Index	-0.0343***	-0.0159*	-0.0328***	-0.0203**
	(0.00895)	(0.00839)	(0.00845)	(0.0103)
Energy Behav. Index	-0.0298***	0.0500***	-0.0247***	0.0579***
	(0.00873)	(0.00824)	(0.00900)	(0.0109)
Envt. Concern Index	0.00232	0.0135	0.000487	0.0151
	(0.00892)	(0.00841)	(0.00858)	(0.0106)
Member Envt. NGO (Yes = 1)	0.0364	0.0530**	0.0383	0.0411
	(0.0256)	(0.0241)	(0.0252)	(0.0286)
Other				
Country Fixed Effects	Yes	Yes	Yes	Yes
Observations	5638	5638	3523	3523

[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

[d]We have also included (but not above-reported) occupation and years of education

Table A.4: Univariate probit regression results for full sample and EU sample. CDD wet-bulb. Air Conditioning and Thermal Insulation. Wealth index and income.

Variable	Full sample				EU sample			
	Air Conditioning		Thermal Insulation		Air Conditioning		Thermal Insulation	
	Wealth index (Sd. error)	Income (Sd. error)	Wealth index (Sd. error)	Income (Sd. error)	Wealth index (Sd. error)	Income (Sd. error)	Wealth index (Sd. error)	Income (Sd. error)
Climate								
Mean HDD (1986-2011)	-1.95e-05	-1.79e-05	-5.23e-06	2.09e-06	-2.96e-05	-3.69e-05*	-1.68e-05	-1.14e-05
	(1.48e-05)	(1.55e-05)	(1.42e-05)	(1.48e-05)	(2.03e-05)	(2.13e-05)	(2.17e-05)	(2.38e-05)
Mean CDD (1986-2011)	-0.000153	-0.000267	-0.000210	-0.000165	0.00561***	0.00504***	-0.00212**	-0.00260**
	(0.000173)	(0.000182)	(0.000168)	(0.000174)	(0.000829)	(0.000907)	(0.00103)	(0.00110)
CDD squared	1.25e-07	2.30e-07	4.11e-09	-3.40e-08	-8.77e-06***	-7.99e-06***	2.64e-06	3.14e-06*
	(1.55e-07)	(1.66e-07)	(1.53e-07)	(1.59e-07)	(1.31e-06)	(1.45e-06)	(1.73e-06)	(1.86e-06)
CDD x HDD	9.84e-07***	9.95e-07***	-5.33e-08	-6.75e-08	-1.71e-06***	-1.52e-06***	9.94e-07*	1.25e-06**
	(9.80e-08)	(1.04e-07)	(9.06e-08)	(9.38e-08)	(3.97e-07)	(4.41e-07)	(5.12e-07)	(5.44e-07)
Socio-economic charact.								
Wealth index	0.113***		0.287***		0.104***		0.294***	
	(0.0105)		(0.0108)		(0.00947)		(0.0133)	
Income		7.17e-07*		1.10e-06***		1.14e-06**		9.35e-07*
		(3.98e-07)		(3.63e-07)		(4.50e-07)		(5.66e-07)
Urban area (Yes = 1)	0.0614***	0.0602***	-0.0142	-0.0272*	0.0384***	0.0355**	-0.0159	-0.0322*
	(0.0147)	(0.0165)	(0.0147)	(0.0157)	(0.0132)	(0.0154)	(0.0177)	(0.0193)
Home size (m^2)		0.000176		0.000738***		0.000285*		0.00104***
		(0.000139)		(0.000133)		(0.000164)		(0.000216)
Home tenure	0.00151***	0.00200***	-0.00171***	-0.00186***	0.00151***	0.00188***	-0.00190***	-0.00206***
	(0.000572)	(0.000656)	(0.000550)	(0.000601)	(0.000511)	(0.000610)	(0.000670)	(0.000752)
Home owner (Yes = 1)	0.0181	0.0824***	0.0818***	0.223***	0.0195	0.0610***	0.0558***	0.186***
	(0.0174)	(0.0178)	(0.0165)	(0.0157)	(0.0160)	(0.0168)	(0.0206)	(0.0205)
Home type (Apt. = 1)	0.0497**	-0.0127	0.0296	-0.117***	0.0515***	-0.00719	0.0570**	-0.102***
	(0.0196)	(0.0205)	(0.0183)	(0.0184)	(0.0179)	(0.0196)	(0.0222)	(0.0234)
Demographics								
Age	-0.000831	-0.000991	0.00280***	0.00232***	-0.00107**	-0.00127**	0.00159**	0.00106
	(0.000557)	(0.000629)	(0.000548)	(0.000587)	(0.000516)	(0.000611)	(0.000675)	(0.000744)
Household size	-0.0165**	0.00392	-0.0425***	0.000360	-0.0204***	-0.00459	-0.0375***	0.00201
	(0.00786)	(0.00876)	(0.00750)	(0.00803)	(0.00779)	(0.00892)	(0.0101)	(0.0112)
Share of under 18	0.136***	0.132***	0.0594	0.0132	0.105***	0.124***	0.0311	-0.00232
	(0.0407)	(0.0458)	(0.0394)	(0.0430)	(0.0377)	(0.0434)	(0.0492)	(0.0549)
Gender (Male = 1)	0.0186	0.0411***	0.0240*	0.0399***	-0.00118	0.0208	0.0284*	0.0427**
	(0.0144)	(0.0159)	(0.0141)	(0.0149)	(0.0132)	(0.0150)	(0.0171)	(0.0186)
Attitudinal charact.								
Envt. Attitude Index	-0.0479***	-0.0495***	-0.00992	-0.0241*	-0.0450***	-0.0501***	-0.0172	-0.0313**
	(0.0120)	(0.0134)	(0.0118)	(0.0125)	(0.0110)	(0.0127)	(0.0147)	(0.0156)
Energy Behav. Index	-0.0184***	-0.0158***	0.0302***	0.0265***	-0.0126***	-0.0120***	0.0369***	0.0296***
	(0.00415)	(0.00465)	(0.00403)	(0.00433)	(0.00394)	(0.00457)	(0.00507)	(0.00557)
Envt. Concern Index	0.000308	-0.000183	0.00924*	0.00847	-0.000131	-0.000542	0.0106*	0.00942
	(0.00500)	(0.00552)	(0.00479)	(0.00516)	(0.00464)	(0.00533)	(0.00605)	(0.00667)
Member Envt. NGO (Yes = 1)	0.0125	0.0274	0.0273	0.0540**	0.0147	0.0316	0.0219	0.0413
	(0.0231)	(0.0254)	(0.0232)	(0.0241)	(0.0214)	(0.0249)	(0.0274)	(0.0287)
Other								
Country fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6780	5638	6780	5638	4436	3523	4436	3523

[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
[d] We have also included (but not above-reported) occupation and years of education

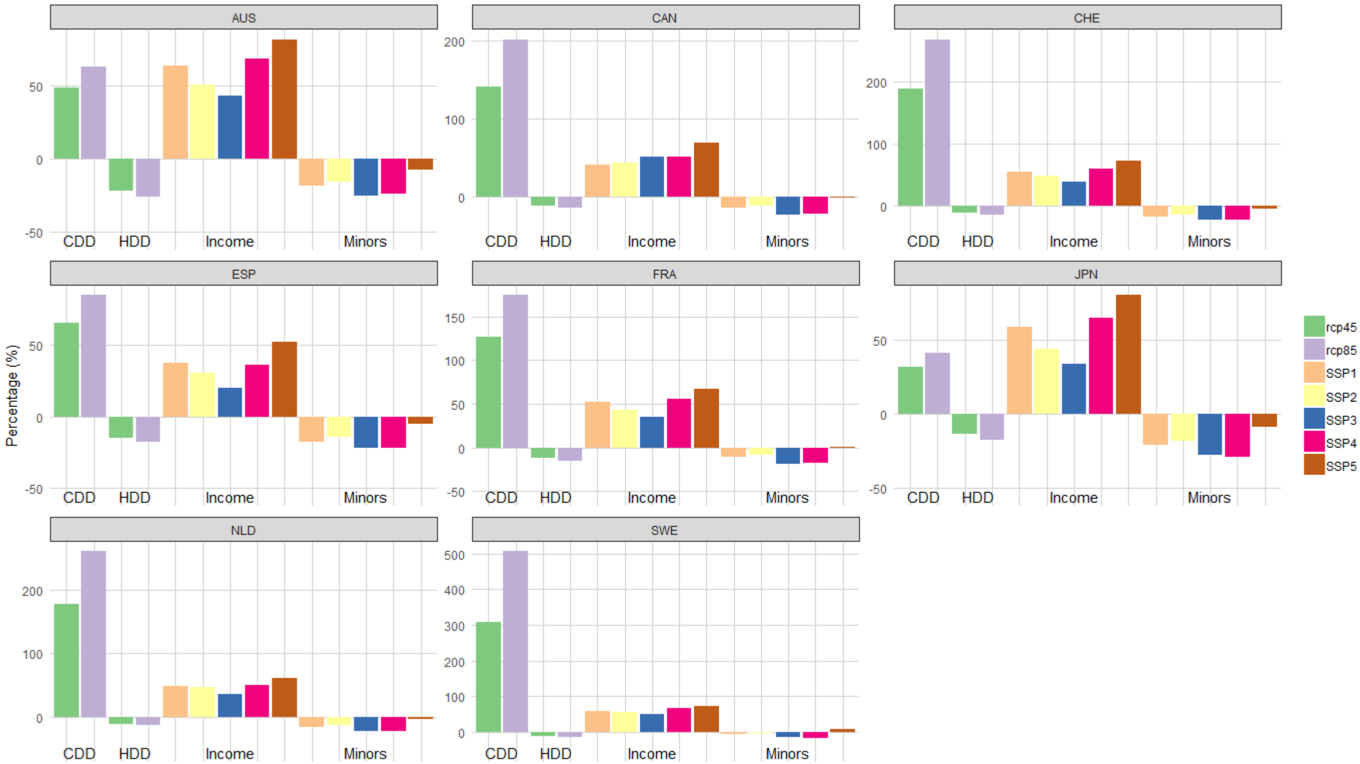

Figure A.4: Percentage change (%) of all drivers in 2020-2060 (CDDs and HDDs between 2021-2060) relative to the historical values (2010 socio-economic variables, 1986-2005 climatic variables).

Table A.5: Historical (2011) and predicted (2020-2060) regional shares of Air Conditioning and Thermal Insulation, mean values.

Variable	Mean	(Std. Dev.)	Min.	Max.	N. of regions
		AUS			
AC share	73.033	(12.124)	50	85.859	7
TI share	58.641	(6.974)	47.547	70	7
Urban share	81.627	(10.2)	65.625	100	7
Minors	15.73	(2.086)	12.644	17.884	7
AC, SSP5—RCP8.5	81.27	(11.451)	60.77	93.460	7
AC, SSP5—RCP8.5 (EU)					0
TI, SSP5—RCP85	55.823	(6.975)	44.728	67.183	7
TI, SSP5—RCP8.5 (EU)					0
		CAN			
AC share	41.834	(16.496)	22.222	67.347	9
TI share	44.548	(13.702)	32.222	77.778	9
Urban share	69.372	(12.631)	42.308	82.222	9
Minors	12.103	(2.626)	8.821	15.541	9
AC, SSP5—RCP8.5	59.877	(19.251)	38.444	94.413	9
AC, SSP5—RCP8.5 (EU)					0
TI, SSP5—RCP85	41.728	(13.703)	29.401	74.960	9
TI, SSP5—RCP8.5 (EU)					0
		CHE			
AC share	10.771	(5.850)	4.762	22.222	10
TI share	46.185	(11.126)	28	66.667	10
Urban share	35.403	(20.878)	4.762	76.19	10
Minors	18.433	(9.961)	2.5	34.896	10
AC, SSP5—RCP8.5	20.062	(6.815)	13.768	33.403	10
AC, SSP5—RCP8.5 (EU)	14.879	(6.23)	8.097	27.032	10
TI, SSP5—RCP85	43.366	(11.127)	25.179	63.848	10
TI, SSP5—RCP8.5 (EU)	47.826	(11.838)	26.466	66.42	10
		ESP			
AC share	44.741	(27.673)	5.263	90	17
TI share	30.842	(7.488)	16.667	46.97	17
Urban share	55.916	(13.082)	27.778	80.892	17
Minors	15.117	(3.992)	8.854	21.97	17
AC, SSP5—RCP8.5	52.487	(27.831)	11.63	97.422	17
AC, SSP5—RCP8.5 (EU)	49.120	(27.755)	9	94.403	17
TI, SSP5—RCP85	28.021	(7.489)	13.844	44.149	17
TI, SSP5—RCP8.5 (EU)	27.549	(7.729)	12.781	44.236	17
		FRA			
AC share	12.952	(8.166)	3.571	31.481	20
TI share	48.594	(7.782)	34.783	59.259	20
Urban share	37.801	(15.302)	7.692	80.078	20
Minors	17.475	(3.85)	12.255	27.87	20
AC, SSP5—RCP8.5	20.888	(8.720)	10.18	39.382	20
AC, SSP5—RCP8.5 (EU)	17.284	(8.44)	7.48	35.996	20
TI, SSP5—RCP85	45.775	(7.782)	31.962	56.44	20
TI, SSP5—RCP8.5 (EU)	45.572	(7.762)	31.757	55.665	20
		JPN			
AC share	84.528	(26.686)	20	100	8
TI share	26.352	(7.043)	18.75	39.535	8
Urban share	63.026	(15.121)	41.667	85.393	8
Minors	13.869	(3.361)	9.739	19.94	8
AC, SSP5—RCP8.5	89.7	(25.024)	28.285	100	8
AC, SSP5—RCP8.5 (EU)					0
TI, SSP5—RCP85	23.531	(7.043)	15.928	36.715	8
TI, SSP5—RCP8.5 (EU)					0
		NLD			
AC share	14.139	(4.765)	6.704	24.742	12
TI share	58.776	(8.504)	47.486	70.732	12
Urban share	41.942	(20.076)	6.897	80.488	12
Minors	14.662	(4.049)	6.140	21.86	12
AC, SSP5—RCP8.5	24.265	(5.813)	14.725	35.959	12
AC, SSP5—RCP8.5 (EU)	18.916	(5.078)	10.888	29.928	12
TI, SSP5—RCP85	55.957	(8.505)	44.666	67.913	12
TI, SSP5—RCP8.5 (EU)	57.234	(8.484)	45.326	69.402	12
		SWE			
AC share	16.613	(6.716)	5	33.333	18
TI share	34.478	(7.967)	20	50	18
Urban share	44.155	(20.26)	6.25	89.844	18
Minors	17.072	(6.239)	8.333	28.417	18
AC, SSP5—RCP8.5	35.089	(10.735)	17.988	53.388	18
AC, SSP5—RCP8.5 (EU)	21.185	(7.383)	8.143	39.314	18
TI, SSP5—RCP85	31.657	(7.967)	17.178	47.181	18
TI, SSP5—RCP8.5 (EU)	43.624	(16.423)	24.444	95.012	18

Table A.6: Absolute and percentage change in the drivers between 2020-2060 relative to the historical average (2010 socio-economic variables, 1986-2005 climatic variables).

Variable	**Mean**	**(Std. Dev.)**	**Min.**	**Max.**	**N. of regions**
CDDs (Change) rcp85	160.822	(97.740)	8.938	387.469	101
HDDs (Change) rcp85	-451.05	(152.687)	-882.995	-110.361	101
CDDs (Change) rcp45	120.878	(80.027)	5.416	310.422	101
HDDs (Change) rcp45	-380.297	(133.625)	-751.042	-92.769	101
CDDs (%) rcp85	222.301	(186.351)	28.805	1160.339	101
CDDs (%) rcp45	148.967	(108.902)	22.041	671.828	101
HDDs (%) rcp85	-16.005	(4.336)	-48.456	-12.218	101
HDDs (%) rcp45	-13.41	(3.536)	-40.732	-9.543	101
Income (%) SSP1	51.043	(8.632)	37.133	63.967	101
Income (%) SSP2	44.856	(7.935)	30.275	55.718	101
Income (%) SSP3	37.356	(9.951)	19.833	50.936	101
Income (%) SSP4	55.213	(10.619)	36.149	68.477	101
Income (%) SSP5	67.771	(8.965)	52.091	81.824	101
Urban share (Change) SSP1	7.399	(3.668)	3.101	13.692	101
Urban share (Change) SSP2	5.966	(1.836)	3.101	9.101	101
Urban share (Change) SSP3	3.712	(1.842)	1.049	6.896	101
Urban share (Change) SSP4	5.966	(1.836)	3.101	9.101	101
Urban share (Change) SSP5	7.399	(3.668)	3.101	13.692	101
Urban share (%) SSP1	6	-	6	6	101
Urban share (%) SSP2	6	-	6	6	101
Urban share (%) SSP3	6	-	6	6	101
Urban share (%) SSP4	6	-	6	6	101
Urban share (%) SSP5	6	-	6	6	101
Minors (%) SSP1	-14.04	(4.84)	-20.47	-5.651	101
Minors (%) SSP2	-11.17	(4.537)	-17.827	-3.311	101
Minors (%) SSP3	-21.035	(3.737)	-27.621	-15.154	101
Minors (%) SSP4	-21.136	(3.489)	-28.583	-16.355	101
Minors (%) SSP5	-1.678	(5.184)	-8.550	7.43	101

Note: Urban share is a constant shifting factor across all SSPs equal to the marginal effect estimated in Table 2.

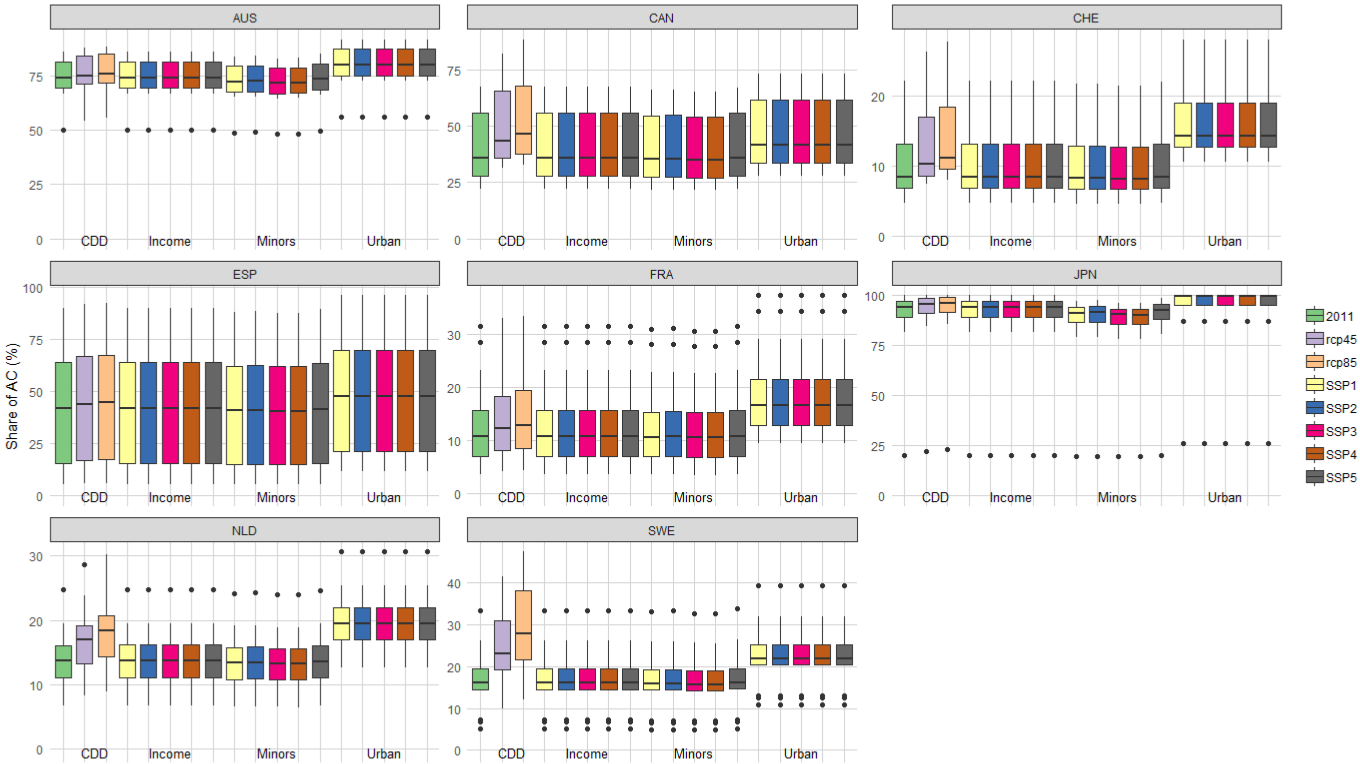

Figure A.5: Actual share of Air Conditioning (2020-2060), full sample estimates. All drivers and scenarios.

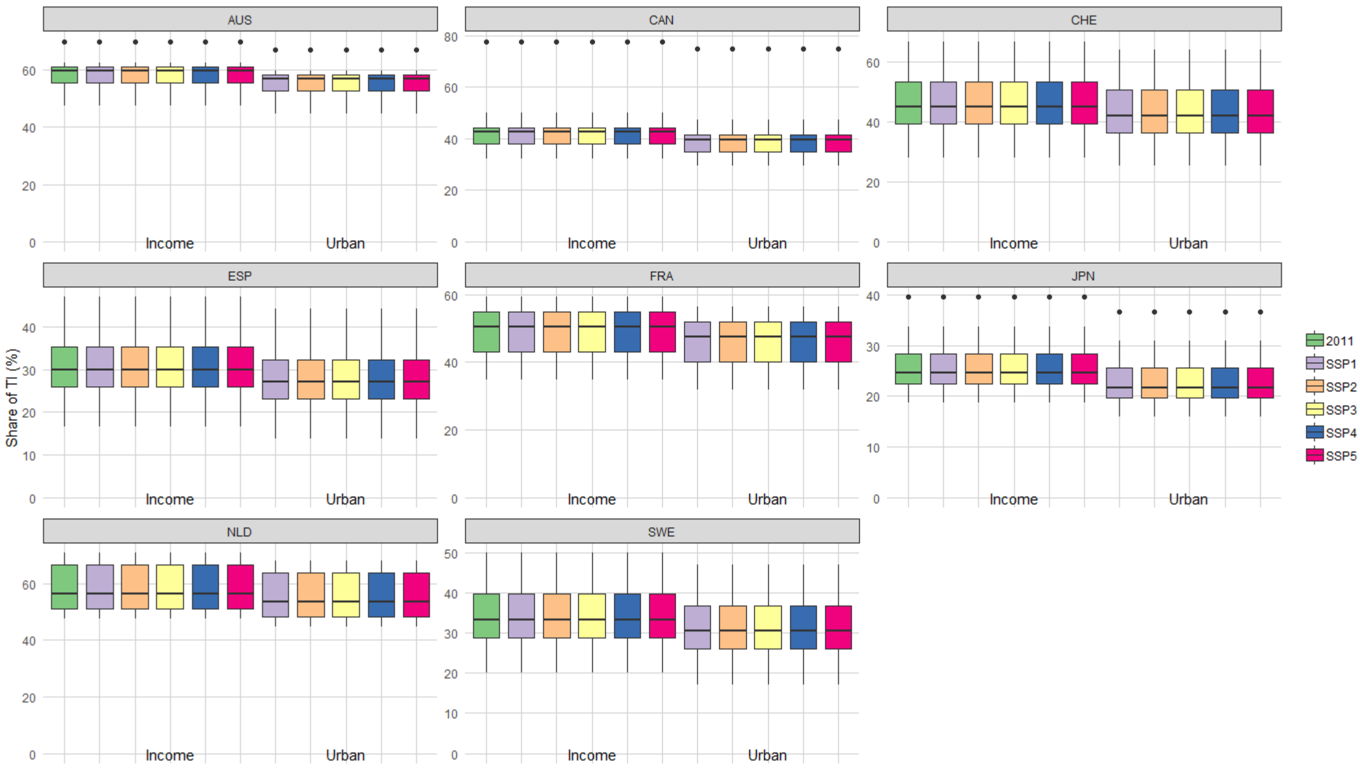

Figure A.6: Actual share of Thermal Insulation (2020-2060), full sample estimates. All drivers and scenarios.

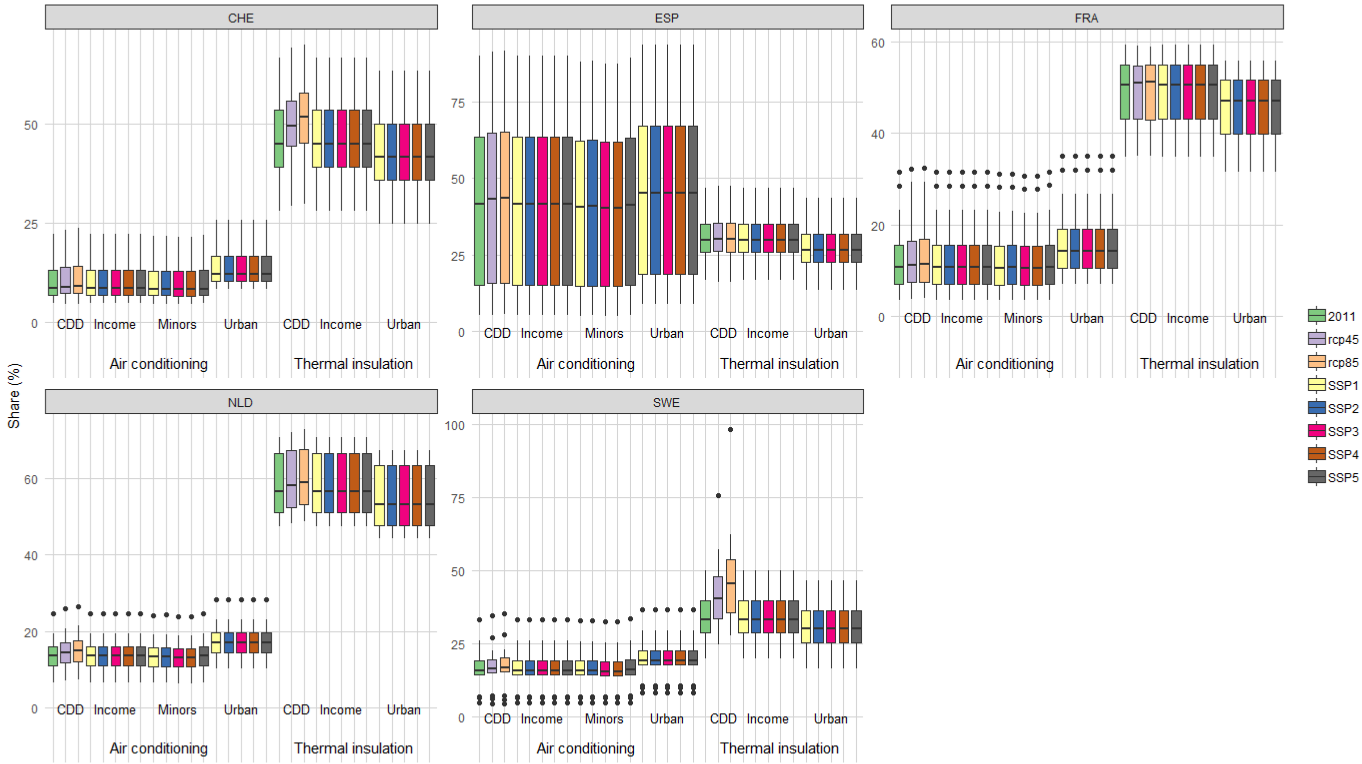

Figure A.7: Actual share of Air Conditioning and Thermal Insulation, EU sample. EU sample estimates. All drivers and scenarios

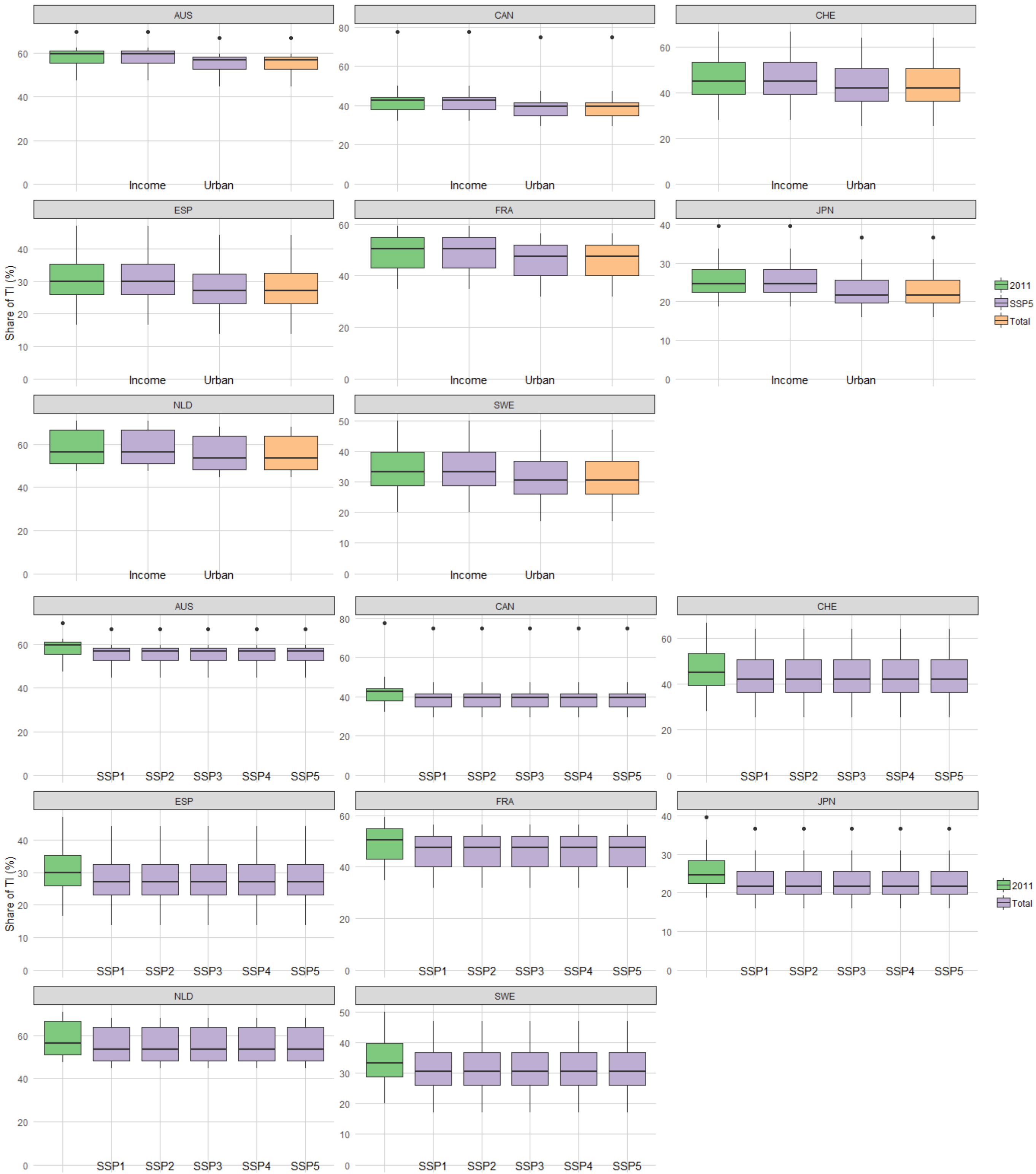

Figure A.8: Projected Thermal Insulation adoption rates around 2040 (2020-2060), full sample estimates.

Note: The statistically significant drivers in the full sample regressions for which quantitative scenarios are available are income and urbanization.