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Adaptation to Climate Variability – Evidence from German Households

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Gerhard Kussel[1]

Adaptation to Climate Variability – Evidence from German Households

Abstract

Using panel data originating from two extensive surveys conducted in 2012 and 2014, we investigate German households' adaptation behavior in response to indoor heat stress during summer months. Providing detailed information of household characteristics, behavior and technical equipment, our unique database allows us to estimate a random-effects probit model on households' vulnerability and adaptive capacity. The estimates indicate that even moderate increases in temperatures are sufficient to trigger investments in adaptation measures: While the propensity to adapt is heterogeneous across socio-economic groups, an increase of one degree Celsius in average summer temperature is associated with a rise of 2.3 percentage points in adaptation probability.

JEL Classification: D12, Q54, R22

Keywords: Climate change; heat stress; panel data; discrete choice models

July 2016

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1 Introduction

It is widely recognized that ecological and social systems are co-evolving (Gual and Norgaard, 2010; Kallis and Norgaard, 2010): Human activities affect ecological systems and vice versa. For example, there is a broad consensus that anthropogenic greenhouse gas (GHG) emissions cause climate change (Stocker et al., 2013), which in turn can have significantly negative impacts on human health (Hajat and Kosatky, 2010; Patz et al., 2005) and economic well-being (Ciscar et al., 2011; Tol, 2009). Thus, the governments of many countries aim at mitigating climate change by reducing GHG emissions, whereas adaptation strategies are designed to cope with the impacts of climate change.

Most public adaptation plans focus on providing information and enhancing private adaptation possibilities (Biesbroek et al., 2010). The success of public adaptation plans, however, crucially depends on the willingness of firms and households to take adaptation measures (Adger, 2003; Marshall, 2013). Yet, despite its high importance, private adaptation is widely understudied.

Using comprehensive survey data, we contribute to the literature by empirically investigating the adaptive behavior of German households' in response to high summer temperatures. We estimate a random-effects probit model, taking account of numerous household characteristics that affect households' vulnerability and adaptive capacity. Relying on cross-sectional variation, our identification strategy rests upon the assumption that the observed adaptation to spatial variation in summer temperatures is a valid proxy for long-term adaptation to climate change. We find that a 1°C increase in average summer temperature is associated with a rise of 2.3 percentage points in adaptation probability.

This result is particularly relevant given the fact that rising temperatures are among the key problems pertaining to climate change. Heat stress during summer months and more frequent heat waves are becoming issues also in the higher latitudes (Fischer and Schär, 2010; Meehl and Tebaldi, 2004; Schär et al., 2004). While the bulk of existing studies that analyze private adaptation behavior focuses on adaptation in climate-sensitive industries, such as the agricultural sector (Leclère et al., 2013; Olesen et al., 2011; Antle et al., 2004), impacts on private households are potentially even more devastating.

Heat stress increases morbidity and mortality (Hajat and Kosatky, 2010), and negatively affects physical and mental performance (Heal and Park, 2013). For instance, the heat wave that hit Europe in 2003 caused more than 70,000 heat-related fatalities (Robine et al., 2008). Future consequences of climate change may be even more serious: Hajat et al. (2014) predict heat-related mortality rates in the UK to increase by more than 250 percent by 2050, depending on the level of adaptation. For Germany, Zacharias and Koppe (2015) find that heat burden will more than double until the end of the century. Zacharias et al. (2014) predict that heat-related mortality due to ischemic heart diseases will increase by a factor of 2.4 to 5.1.

Given the potentially dramatic consequences of increasing heat stress, successful adaptation is needed, especially for groups with high vulnerability (Kovats and Kristie, 2006; Zacharias et al., 2014). According to Barreca et al. (2013), the decline in heat-related death rates of more than 80 percent in the US over the 20th century can almost completely be explained by the dissemination of residential air conditioning. Since empirical analyses of adaptation behavior are missing, though, it remains unclear whether people respond to temperature changes and which determinants drive their behavior (Ford et al., 2011; Berrang-Ford et al., 2011). In the absence of better evidence, adaptation usually enters impact assessments via arbitrarily designed scenarios (Hajat et al., 2014; Moss et al., 2010; Zacharias et al., 2014).

Reliable insights in adaptive behavior are also relevant for choosing the right level of mitigation efforts: Neglecting or underestimating the benefits of adaptation may lead to an overestimation of the negative impacts of climate change (Hasson et al., 2010). Hence, it is important to know to what degree individuals adapt to a changing climate.

In Section 2, we present the database and define the variables of interest. The empirical methodology is described in Section 3, followed by the discussion of our results in Section 4, including some robustness checks. We close with a brief summary and conclusions.

2 Data

The analysis mainly builds on extensive data from two household surveys, conducted in the fall of 2012 and the summer of 2014.[1] To gather the information on adaptation behavior, we collaborated with the professional survey institute *forsa*, which maintains a constantly refilled household panel that is representative for the German population older than 14.[2] In total, our sample encompasses 9,690 observations. While 3,698 households participated in both surveys, 1,161 households participated in the 2012 survey alone and 1,133 solely in the 2014 survey.

Using a state-of-the-art tool, *forsa* allows respondents to fill out the questionnaire using either the internet or, if access is unavailable, a television. Households retrieve and return questionnaires from home and can interrupt and continue the survey at any time. Based on visually supported questionnaires, households provide in-depth information on their attitudes towards climate change, technical endowment of their building, and their housing situation.[3] This data is completed by a large set of regularly updated socio-economic and demographic characteristics, which are available from *forsa*'s household selection procedure. The survey aims at interviewing the head of the household, defined as the person reporting to be responsible for the household's decisions. As a result, there are more males than females in our sample.

To measure adaptation, we analyze information on measures with which households attempt to ameliorate the negative effects of high temperatures. Such measures include ventilators, reflective films and anti-sun glass at the windows, air conditioners, and green roofs. We define a binary indicator of adaptation, taking on the value of one if a household has implemented at least one such measure and zero otherwise. Eighteen percent of the sample households had implemented some of these adaptation measures in 2012, a share that increased to 25 percent in 2014.

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[1] The establishment of the household panel on adaptation to climate change and energy consumption is a part of the project *Evaluating Climate Mitigation and Adaptation Policies (Eval-MAP)*, www.rwi-essen.de/eval-map.

[2] Information on the panel is available at http://www.forsa.com/.

[3] For further information on the questionnaire, in German, see Osberghaus and Philippi (2015).

Drawing on the adaptation literature (Adger et al., 2003; Brooks et al., 2005; Smit and Wandel, 2006; Osberghaus, 2015), we exploit information on the most important socio-economic factors of vulnerability and adaptive capacity . Specifically, as control variables, we include gender, employment status, years of education, age and body weight of household heads, households' net income, and a range of housing characteristics (Table 1).[4]

Using information on population figures from the Federal Statistical Office (DESTATIS), we derive an indicator of urban areas, defined as those areas whose population density is higher than 500 inhabitants per km^2.

Table 1: Descriptive Statistics

	Mean	Standard Deviation	Minimum	Maximum
Adaptation indicator	0.22	-	0	1
Summer temperature (in °C)	17.76	0.89	9.93	19.99
Income (in 1000 €)	2.93	1.35	0.25	5.75
Female	0.30	-	0	1
Employment	0.67	-	0	1
Years of education	12.63	3.88	8	18
Age under 30	0.07	-	0	1
Age over 60	0.30	-	0	1
Body weight (in kg)	83.15	16.99	39.00	220.00
Household size	2.21	1.09	1	20
House	0.47	-	0	1
Attic	0.14	-	0	1
Ownership	0.57	-	0	1
Urban area	0.38	-	0	1
Number of Observations	9,690			

Additionally, we use data from Germany's national meteorological service *Deutscher Wetterdienst* (DWD). The data includes information on the daily average temperature for all days between January 1, 2008, and December 31, 2014, as well as the exact coordinates of each of the 485 weather stations in the database. To measure heat stress, we calculate the local average summer temperature, defined as the moving average of daily temperatures in June, July and August of the last 4 years. To obtain average summer temperatures for each of the 8,270 German postcode regions, we identify the coordinates

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[4] Information on income is provided in equidistant categories. To derive a continuous variable, this information is recoded according to the category means.

of the geographic centroid of each area and calculate the distance to each weather station. The squared inverse of these distances is used as weights for the spatial interpolation of the temperatures:

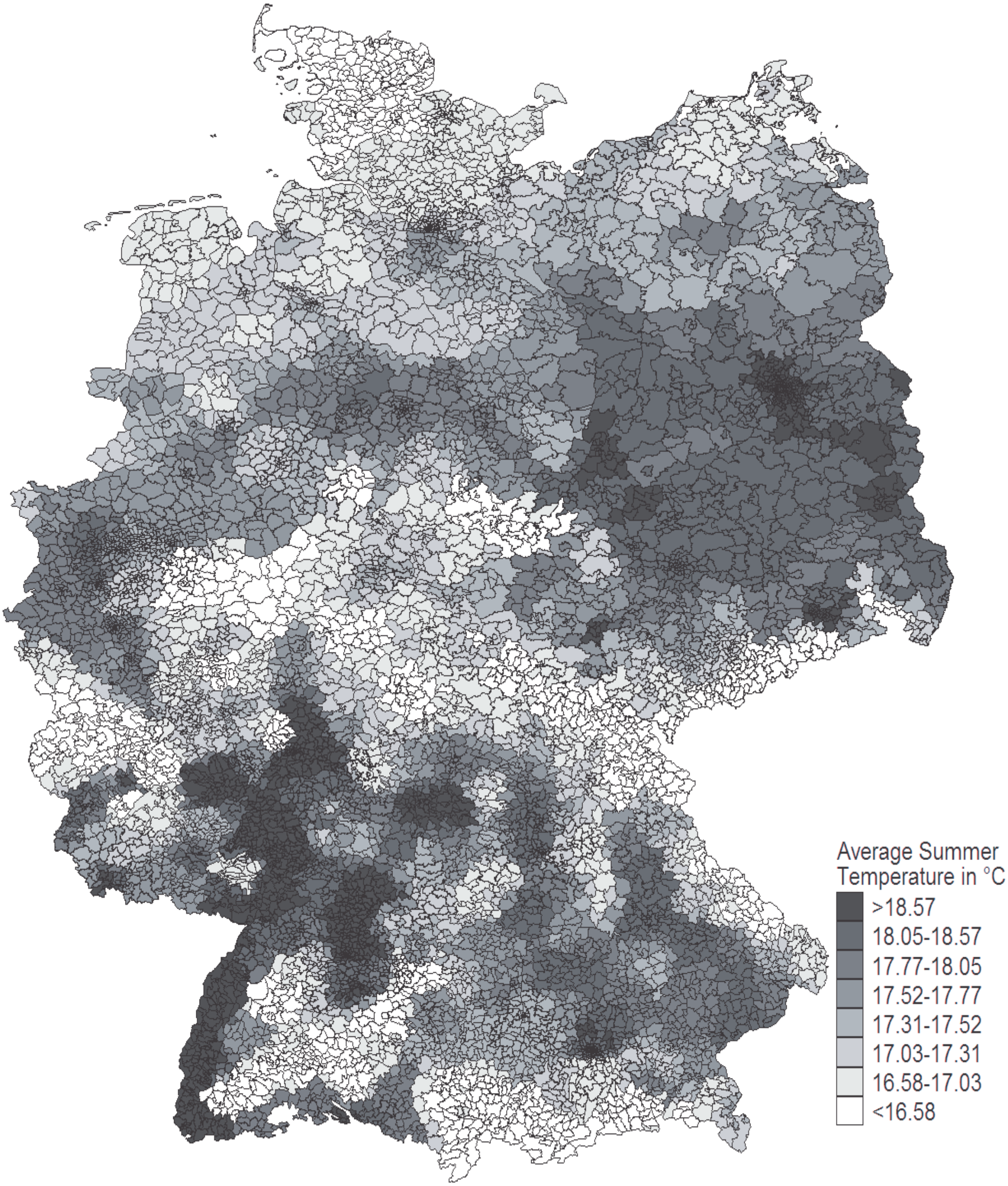
$$temp_i = \sum_{j=1}^{3} \frac{temp_j * \frac{1}{distance_{ij}^2}}{\sum_{j=1}^{3} \frac{1}{distance_{ij}^2}},$$

where the temperature in post code region *i* is calculated as the average of the measured temperatures of the nearest three weather stations *j=1-3*, weighted by the inverse of their squared *distance* to the postcode region's centroid.

While the weather stations are evenly distributed across Germany, there are substantial regional differences in temperature (Figure 1). The coastal areas in the north, for instance, exhibit an average summer temperature of below 16°C, whereas the warmest regions around Berlin and the Rhine Valley in *Baden-Württemberg* enjoy average temperatures of over 19°C.

Recognizing that climate change impacts are difficult to predict, this difference of about 3°C roughly matches the changes in average temperatures due to climate change by 2100. In its fifth assessment report, the IPCC predicts an increase in average temperature in Germany by 2 to 3°C under a scenario with a global convention for GHG emissions reduction. Without such a convention, the increase in temperature will be higher (Stocker et al., 2013). While temperature changes vary across regions, the strongest rise in temperature is expected for South Germany (Zacharias and Koppe, 2015). In the subsequent section, we employ cross-sectional variation in adaptation to summer temperatures as a proxy to gauge adaptive behavior to long-term changes in temperature levels.

Figure 1: Interpolated Average Summer Temperature in °C



3 Methodology

A key reason for the scarce literature on private adaptation behavior is that data with a time horizon of more than 30 years are required to allow for analyzing behavioral responses to climate change.[5] Due to the absence of such data, we use households' adaptation to today's regional climate variability as a proxy for future adaptation behavior when temperatures increase as predicted by the IPCC scenarios - an approach called forecasting by analogy (Ford et al., 2010; Burton, 1997; Feenstra et al., 1998; Glantz, 1991).

To this end, we rely on the cross-sectional variation in temperature and adaptation behavior of German households, as reflected by the data described in the previous section. Accordingly, our identification strategy rests upon the assumption that the observed adaptation to spatial variation in summer temperatures is a valid proxy for the long-term adaptation to climate change. This holds true if temperature perception does not change over time. For example, without technical adaptation, the degree of heat stress caused by a temperature of 30°C has to be the same in 2010 and 2050. Additionally, we assume that differences in average summer temperature do not drive interior migration in Germany, as temperature-driven migration would result in differences in temperature perception across Germany. As unobserved regional characteristics, such as cultural norms and different regulations, may be correlated with the average temperature of post code regions, potential omitted variable bias may arise. We address this issue by including federal state dummies to capture all unobserved time-invariant differences at federal state levels.

Taking into account that households' propensity of adaptation is unobservable, we design the following latent variable model:

$$adaptation*_{it} = \alpha \ temp_{it} + \mathbf{x}'_{it}\boldsymbol{\beta} + \gamma_t + \varepsilon_{it},$$

where $adaptation*$ is the unobservable propensity of adaptation for household i at time t, α is the coefficient on the local average summer temperature ($temp$). $\boldsymbol{\beta}$ designates

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[5] According to the *World Meteorological Organization (WMO)*, climate is the average weather over a period of 30 years.

the vector of coefficients corresponding to household characteristics $\mathbf{x}$, γ denotes a time dummy to capture year-specific effects and ε is the error term consisting of the unobserved household random effect δ and the random error term η:

$$\varepsilon_{it} = \delta_i + \eta_{it}.$$

Although households' propensity to adapt is unobservable, we can observe whether a household has implemented adaptation measures:

$$adaptation_{it} = \begin{cases} 1 & \text{if } adaptation^*_{it} > 0, \\ 0 & else, \end{cases}$$

where *adaptation* is our binary adaptation indicator.

In our preferred specification, we estimate this latent variable model using a random-effects probit approach.[6] In addition, to test the robustness of the results, we estimate a pooled linear probability model and a linear random effects model. These linear models do not account for the binary nature of the dependent variable, but require no assumption on the underlying non-linear relationship (Wooldridge, 2009).

4 Results and Discussion

This section presents the average marginal effects of the determinants of the adaptation behavior of German households, with the average being computed as the means of the marginal effects across all observations. (Coefficient estimates are reported in Table A.1 of the appendix.) As can be seen from Table 2, all employed estimators produce very similar results with respect to size and statistical significance of the marginal effects.

Throughout all model specifications, average summer temperature has a statistically significant positive effect on the probability of adopting adaptation measures. In our

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[6] We use the Stata command xtprobit that makes use of the adaptive Gauss-Hermit quadrature. To get a stable quadrature approximation, we set iteration points to 17.

Table 2: Average Marginal Effects of the Determinants of Adaptation Behavior to Heat Stress

	Random-Effects Probit	Random-Effects Linear Probability Model	Pooled Linear Probability Model
Summer temperature (in °C)	0.0231***	0.0242***	0.0219***
	(0.0064)	(0.0062)	(0.0057)
Income (in 1000€)	0.0123***	0.0131***	0.0126***
	(0.0041)	(0.0041)	(0.0039)
Female, dummy	-0.0370***	-0.0306***	-0.0295***
	(0.0116)	(0.0109)	(0.0098)
Employment, dummy	-0.0347***	-0.0340***	-0.0363***
	(0.0131)	(0.0128)	(0.0121)
Years of education	-0.0059***	-0.0056***	-0.0054***
	(0.0013)	(0.0012)	(0.0011)
Age under 30, dummy	-0.0504**	-0.0331**	-0.0403***
	(0.0203)	(0.0149)	(0.0140)
Age over 60, dummy	-0.0856***	-0.0861***	-0.0914***
	(0.0141)	(0.0134)	(0.0134)
Body weight (in kg)	0.0019***	0.0020***	0.0021***
	(0.0003)	(0.0003)	(0.0003)
Household size	-0.0083*	-0.0085*	-0.0084*
	(0.0047)	(0.0046)	(0.0043)
House, dummy	0.0531***	0.0439***	0.0460***
	(0.0131)	(0.0130)	(0.0125)
Ownership, dummy	0.0806***	0.0823***	0.0826***
	(0.0128)	(0.0125)	(0.0116)
Attic, dummy	0.1126***	0.1091***	0.1126***
	(0.0136)	(0.0135)	(0.0134)
Urban area, dummy	0.0060	0.0051	0.0075
	(0.0116)	(0.0116)	(0.0104)
Year 2014, dummy	0.0558***	0.0545***	0.0559***
	(0.0071)	(0.0068)	(0.0083)
State dummies included	Yes	Yes	Yes
Number of Observations	9,690	9,690	9,690

*Note: Robust standard error are in parentheses; * p<0.1 ** p<0.05 *** p<0.01*

preferred specification, the probability of adaptation increases by 2.3 percentage points for each additional degree in average summer temperature. These results provide evidence that even under the moderate climate conditions in Germany, households adapt to differences in average temperatures.

Moreover, most of the socio-economic variables show the expected signs. For example, income is found to be a driver of adaptive capacity with each 1,000 € increase in income associated with a 1.2 percentage point increase in the probability of adaptation. Other variables, such as age, measure the households' vulnerability, rather than their ability to adapt. Despite being more sensitive to heat stress, elderly people show a 8.5 percentage point lower adaptation probability. This result indicates a lower adaptive capacity and is explained e.g. by Bassil and Cole (2010), who conclude that elderly people are insufficiently reached by programs that provide adaptation incentives.

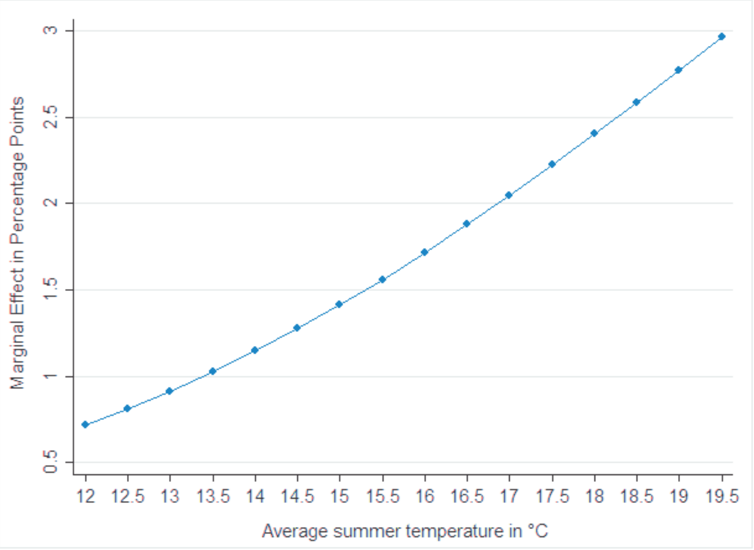
As employment commonly reduces the time spend at home, being employed with more than 20 hours a week lowers the adaptation probability by 3.4 percentage points. Given that direct solar radiation may drastically increase temperatures, households living in the attic have a 11.2 percentage points higher adaptation probability than other households.

Since investments in adaptation measures not only lower heat burden, but also increase the value of the property, ownership has a positive impact on the probability to take adaptation measures. Finally, we find a small, but statistically significant negative effect of years of education on adaptive behavior.

To investigate the validity of our results, we perform several robustness checks reported in Table A.2 in the appendix. The results reveal that redefining both the adaptation-indicator and the temperature variable do not substantially change the effect of temperature on the probability of adaptation.

Finally, in non-linear models, such as the probit model, marginal effects are typically not constant. To gain further insights in the effect of temperature on the probability of adaptation, Figure 2 illustrates the variation in the marginal effects across a temperature range between 12 and 19.5°C. It becomes evident that the marginal effect grows with temperature. Hence, as climate change will induce an upward shift of the whole temperature distribution, it is likely to trigger even larger adaptation effects than given by the average effect found in this analysis.

Figure 2: Marginal Effects of Average Summer Temperature in °C on Adaptation Probability



5 Summary and Conclusion

By lowering individuals' mental and physical performance and increasing the risk of heat-related morbidity and mortality, heat stress has strong negative effects on human welfare. The heat burden is likely to increase in many countries of the world owing to climate change. Therefore, in addition to efforts to mitigate climate change, more attention should be paid to strategies for adapting to its impacts. Yet, despite its high potential to extenuate negative effects, private adaptation is widely understudied. A key reason is that data on private adaptation activities is lacking, as climate change and adaptation to its consequences are long-run processes.

Exploiting cross-sectional differences in adaptive behavior, we provide evidence for adaptation at the household level, relying on the assumption that the observed adaptation to spatial variation in summer temperatures is a valid proxy for the long-term adaptation to climate change. Our estimate of an increased adaptation probability of 2.3 percentage point per degree Celsius illustrates that German households, which face moderate climate conditions, respond to variations in average summer temperatures.

Furthermore, we find differences with respect vulnerability and adaptive capacity across socio-economic groups. For instance, elderly people show a low probability of adaptation despite their high vulnerability. Therefore, adaptation policies that target such groups may yield particularly high benefits.

In conclusion, our results demonstrate that it is essential to account for the adaptive response of private households in predictions of climate change impacts. Neglecting private adaptation would lead to an overestimation of the predicted negative effects of climate change.

Appendix

Table A.1: Coefficient Estimates of the Determinants of Adaptation Behavior to Heat Stress

	Random-Effects Probit	Random-Effects Linear Probability Model	Pooled Linear Probability Model
Summer temperature (in °C)	0.1474***	0.0242***	0.0219***
	(0.0412)	(0.0062)	(0.0057)
Income (in 1000 €)	0.0788***	0.0131***	0.0126***
	(0.0262)	(0.0041)	(0.0039)
Female, dummy	-0.2363***	-0.0306***	-0.0295***
	(0.0735)	(0.0109)	(0.0098)
Employment, dummy	-0.2213***	-0.0340***	-0.0364***
	(0.0835)	(0.0128)	(0.0122)
Years of education	-0.0375***	-0.0056***	-0.0054***
	(0.0083)	(0.0012)	(0.0011)
Age under 30, dummy	-0.3216**	-0.0331**	-0.0403***
	(0.1291)	(0.0149)	(0.0140)
Age over 60, dummy	-0.5464***	-0.0861***	-0.0914***
	(0.0892)	(0.0134)	(0.0126)
Body weight (in kg)	0.0123***	0.0020***	0.0021***
	(0.0019)	(0.0003)	(0.0003)
Household size	-0.0531*	-0.0085*	-0.0084*
	(0.0298)	(0.0046)	(0.0043)
House, dummy	0.3393***	0.0439***	0.0460***
	(0.0828)	(0.0130)	(0.0125)
Ownership, dummy	0.5147***	0.0823***	0.0826***
	(0.0815)	(0.0125)	(0.0116)
Attic, dummy	0.7187***	0.1091***	0.1126***
	(0.0857)	(0.0135)	(0.0134)
Urban area, dummy	0.0381	0.0051	0.0075
	(0.0742)	(0.0116)	(0.0104)
Year 2014, dummy	0.3562***	0.0545***	0.0559***
	(0.0448)	(0.0068)	(0.0083)
State dummies included	Yes	Yes	Yes
Number of Observations	9,690	9,690	9,690

*Note: Robust standard error are in parentheses; * $p<0.1$ ** $p<0.05$ *** $p<0.01$*

Table A.2: Average Marginal Effects of the Determinants of Adaptation Behavior to Heat Stress - Robustness Checks

	Preferred RE-Probit	Share Days > 19°C	Self-Conducted Measures Only	Without Interpolation
Summer temperature (in °C)	0.0231***	-	0.0181***	0.0204***
	(0.0064)	-	(0.0051)	(0.0059)
Share of days >19°C (in %)	-	0.0020***	-	-
	-	(0.0007)	-	-
Income (in 1000 €)	0.0123***	0.0123***	0.0069**	0.0124***
	(0.0041)	(0.0041)	(0.0032)	(0.0041)
Female, dummy	-0.0370***	-0.0368***	-0.0257***	-0.0370***
	(0.0116)	(0.0116)	(0.0091)	(0.0116)
Employment, dummy	-0.0347***	-0.0347***	-0.0314***	-0.0348***
	(0.0131)	(0.0131)	(0.0103)	(0.0131)
Years of education	-0.0059***	-0.0059***	-0.0046***	-0.0059***
	(0.0013)	(0.0013)	(0.0010)	(0.0013)
Age under 30, dummy	-0.0504**	-0.0505**	-0.0378**	-0.0506**
	(0.0203)	(0.0203)	(0.0164)	(0.0203)
Age over 60, dummy	-0.0856***	-0.0857***	-0.0648***	-0.0859***
	(0.0141)	(0.0141)	(0.0114)	(0.0141)
Body weight (in kg)	0.0019***	0.0019***	0.0016***	0.0019***
	(0.0003)	(0.0003)	(0.0002)	(0.0003)
Household size	-0.0083*	-0.0083*	-0.0090**	-0.0083*
	(0.0047)	(0.0047)	(0.0037)	(0.0047)
House, dummy	0.0531***	0.0535***	0.0318***	0.0533***
	(0.0131)	(0.0131)	(0.0100)	(0.0130)
Ownership, dummy	0.0806***	0.0803***	0.0644***	0.0803***
	(0.0128)	(0.0128)	(0.0103)	(0.0128)
Attic, dummy	0.1126***	0.1124***	0.0637***	0.1130***
	(0.0136)	(0.0136)	(0.0107)	(0.0136)
Urban area, dummy	0.0060	0.0075	0.0015	0.0061
	(0.0116)	(0.0117)	(0.0090)	(0.0116)
Year 2014, dummy	0.0558***	0.0572***	0.0525***	0.0560***
	(0.0071)	(0.0071)	(0.0061)	(0.0071)
State dummies included	Yes	Yes	Yes	Yes
Number of Observations	9,690	9,690	9,597	9,690

*Note: Robust standard error are in parentheses; * p<0.1 ** p<0.05 *** p<0.01*

Column one of Table A.2 repeats the results of our preferred probit estimation. In the second specification the temperature variable is not defined as mean summer temperature, but as share of summer days with a daily average temperature above 19°C. This modification takes into account that the urgency to adapt may not depend on the average level of temperature, but on temperature extremes. A model with both variables included suggests that households adapt to average temperature level and not to temperature extremes. However, both variables are highly correlated.

Since pre-installed adaptation measures may play a minor role for the choice of housing, column three presents a model where the dependent variable is limited to self-conducted measures, after moving to the current home.

No inverse distance weighting of the measured temperature is performed in the specification reported in column four. Instead, the measured temperature of only the next weather station is used to illustrate that the results are not driven by method of interpolation or number of weather stations selected.

Through all designs, the results are statistically significant and the differences between them are negligible.

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