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Climate Change Adaptation and Residential Electricity Demand in Europe

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Abstract: Temperature influences our notion of comfort. The ways we equip and heat and cool our homes in part reflect this. This paper views electricity use in part as a phenomenon of adaptation to changes in weather. This allows us to provide estimates of climate change impacts on electricity consumption in Europe. Constructing a data set on weather across a panel of European countries, we employ a concept of comfort which relates electricity consumption to outdoor temperatures, to estimate the parameters of electricity demand. Random variations in weather have a statistically significant impact on electricity demand from households and services. The results suggest that changes in electricity use due to climate change will be far from dramatic. Northern Europeans will reduce their heating demand and Southern Europeans will increase their cooling demand. On average, the results suggest that climate change will reduce European energy demand. But the magnitude of this net benefit is small, and likely less important than other changes (income, technology) as well as the more disaggregate effects (by country, by season, etc). A result of our study is unbiased electricity demand parameters, with elasticities of about 80% and negative 20% for income and price, respectively**.**

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1 Introduction

Economists are often called upon to supply essential input to policy making, including on the economic impacts of climate change and the possibilities for adapting to these changes. In a related study, Eskeland, Rive, and Mideksa (2008) show that the European power production sector will play an instrumental role in the European abatement of greenhouse gases. However, since for the electricity sector both the supply side and the demand side have physical assets in the landscape, the electricity sector will be affected not only by greenhouse gas abatement policies, but also by the geophysical impacts of climate change and adaptation strategies.

This study focuses on the demand side, with relevance both for abatement policies and for impacts and adaptation. If the power sector is to reduce its emissions by a given rate, parameters of the demand system are relevant both for projections of demand and for the welfare costs of demand reductions (or manipulation) as part of a mitigation strategy. At certain levels of income growth, what are the implications for emissions through electricity demand? And if we experience a certain pattern of climate change, what is the extent of adaptive responses in terms of electricity needed for cooling?

The answers to these questions are pursued in this paper. A first step is to start with an explicit microeconomic model, aiming at including impacts and adaptation in an optimizing framework. Using a data set that has not been used for such purposes before (Eurostat), and constructing new data sets based on historic and scenario-based climate data, we estimate demand parameters. We can then estimate the potential impact of climate change on electricity demand. The central story is that outdoor temperature has a statistically significant impact on power consumption. With a warmer climate in Europe there will be greater demand for cooling and reduced demand for heating. Also, growing income will lead to increased power consumption, an effect that is quantitatively much greater than the effects of climate change. The responsiveness of electricity consumption to changes in price is quite low compared with its sensitivity to changes in income.

2 Motivation

An important question in policy making related to mitigation of or adaptation to climate change is how agents may respond to various policy measures. Climate change mitigation entails measures aimed at reducing the use of inputs or outputs that raise the level of atmospheric concentration of GHGs.

Electricity consumption is an important factor with regard to the emissions of GHGs. Sector wise, power production in most countries is responsible for higher GHG emissions than any other sector due to its reliance on fossil fuels. For instance, more than 50% of Europe’s and 70% of the US’s electricity is produced using fossil fuel fired power plants. About 40% of European emissions of CO2, the dominant GHG, stem from electric power production.

Besides being a major source of GHG emissions, electricity consumption also provides opportunities for adapting to climate change. People use electricity-consuming cooling equipment such as central air conditioning units, freezers, and refrigerators, and electricity is also used for heating residential houses and other buildings. In Norway, more than 80% of the business buildings and residential homes use electricity for heating, but in many countries electricity for heating is less important. For cooling, electricity dominates more generally. According to Bertoldi and Atanasiu (2007) about 27% of Europe’s residential electricity consumption is devoted to heating and cooling of residential houses. Due to this role of electricity in modifying the impacts of changes in outdoor temperatures, a study of electricity demand offers – inter alia - information about opportunities for adaptation to climate change.

An important question is what the impact of climate change on electricity consumption is. Large changes in temperature are rare, and as Mansur et al. (2008) note, the cross country variations in temperature can be a proxy. If data points from each country are used, it would enable a type of estimate for the impact of changes in temperature based. That is, if one were to focus on a single country, say Iceland, which presently has zero cooling demand, it would be impossible to learn anything about the impact of prospective climate change through cooling demand from historical data. However, if Iceland's electricity consumption is used in the context of a larger set of countries that includes Italy and the Netherlands, it may be possible to infer partial results on changes in cooling demand in the case of climate change.[1] However, the analyst then faces the challenges of differences between Iceland and Italy that are unrelated to the temperature differences, challenges that place clear demands both on the data set and on the approaches used for inference in the comparison. This approach nevertheless provides an opportunity to contribute to our understanding of impacts of climate change which would otherwise be left to speculation. Estimates of impacts are necessary inputs for measuring the costs and benefits of climate change, and can hopefully be valuable for policy evaluation.

Such estimates are also essential inputs for integrated assessment and to integrate the impact of climate change into global and regional macroeconomic models. This requires the integration of climate variables in both the supply and demand sides of the models. Currently, this aspect is lacking from the models mainly due to absence of empirical estimates of elasticities.[2] Our first contribution to the literature is to test whether climatic variables have an impact on electricity consumption, using a rich panel data set from European countries. To the best of our knowledge, there is no study that uses Europe-wide data set to answer the questions of interest. Due to the span of European countries in terms of latitude and income levels, the study should also have interest from the perspective of broader applications.

Second, it is also important to measure how agents adjust their production and consumption behavior in response to changes in policy instruments that raise the relative prices of GHG-emitting products. Important aspects of mitigation policies are guided by how agents respond to changes in prices. Such policies should be informed by quantitative estimates of price elasticities of demand.[3]

Most of the existing estimates of price elasticity of electricity demand (such as very careful studies by Asadoorian et al (2007), Mansur et al.(2008), and Reiss and White (2005)) could potentially be biased either due to simultaneity or omitted variables that are correlated with electricity prices and electricity demand. An important example is that cooling degree days affect both electricity prices and electricity demand; thus estimates of price elasticities that have not controlled for temperature variables could be subjected to omitted variable bias. By controlling for climate variables that are correlated to electricity demand and prices, potentially omitted variables, and using exogenous instrument for price, our study also offers unbiased estimates of price elasticities of demand for electricity.

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[1] In support of this point, Mansur et al. (2008) point out that "Ideally, one might be interested in a dynamic model and panel data to better evaluate consumers' choices, but climate change occurs very slowly and panel data do not exist for energy use."

[2] While there are large number of papers that estimate seasonal temperature effects on electricity demand, it is not clear how their results can be used for economic analyses of issues related to climate change. The main problem is that it is very hard to harmonize the outputs of climate models, i.e. mainly annual temperature, and the estimates of such seasonal/national demand parameters without imposing strong assumptions. We overcome this problem by using national annual heating and cooling degree days instead of seasonal temperature.

[3] Sandmo (1975) is the classical reference on how demand parameters determine optimal taxation of polluting goods (or of pollution). Taylor (1975) contains a good review of the literature of relatively older papers while Kamerschen, and Porter (2004) reviews the latest studies. Early attempts to study the demand for electricity include Fisher and Kaysen (1962), Hauthakker and Taylor (1970), Taylor (1975), Taylor et al (1977), Taylor (1979), Berndt (1978), Halvorsen (1975), and Bohi (1984). Reiss and White (2005) use very detailed microeconomic data from California to estimate households' electricity demand taking into account nonlinear pricing, heterogeneity, and aggregation. Asadoorian et al (2007) also estimate the urban and rural demand for electricity using detailed microeconomic panel data for China. Among commodities subject to econometrically estimated systems, energy (fuels, electricity) are heavily represented, not so much for reasons of environment or climate as for other reasons (energy security, investment planning, regulation). But examples of environmentally motivated studies also exist. Pitt (1985) estimated demand for kerosene in Indonesia, to indicate that kerosene subsidies were not very well suited to prevent deforestation. Eskeland, Jimenez and Liu (1993) estimated an energy demand system for industries, to study the responsiveness of air pollutants to fuel prices. Eskeland and Feyzioglu (1997) estimated a model of vehicle ownership and use to study the role of demand management in air pollution control. In the work of Jorgenson and Wilcoxen (1991) on the costs to the US economy of reducing emissions, an empirically estimated energy demand system plays a central role.

Thirdly, our study offers income elasticity estimates for which the problems of measurement error and omitted variables are carefully considered and handled. There has been a strong interest and heated discussion about the link between electricity consumption and income (for instance the growth in China and India) and its likely impact on electricity consumption and hence emissions on the other. The parameter at the center of attention in this debate is the responsiveness of electricity demand to income growth. Though income affects electricity demand, the magnitude as suggested by the existing estimates is biased for different reasons.

There are legitimate concerns over measurement errors associated with the use of per capita income. Moreover, income is correlated to temperature through geographical characteristics, which may or may not be constant over time. For example, people consume more electricity for ventilation in the south than in the north, reflecting an association between climate and electricity consumption. Climate is also strongly correlated with average income through geography.[4] Unless the climate variable is controlled, the income elasticities could reflect the relationship between climate and consumption rather than income.[5]

Finally, our estimated model can be used along informed climate scenarios to provide estimates of electricity consumption under climate change. Basically, we follow a standard strategy in the literature, for example like Deschenes and Greenstone (2007); i.e. we use climate change predictions from climate models and combine these with our estimated impacts of cooling and heating degree days on electricity demand in Europe.

The rest of this paper is organized as follows. First, we specify the theoretical framework over which we organize our discussion of the impact of climate change; we then provide a brief description of the source and the statistical properties of the data we use. Next, we describe our econometric strategy. We finally present the discussion of results related to the estimation of parameters and the impact of climate on electricity demand, accompanied by concluding remarks.

3 Theoretical Model

The theoretical framework we follow involves standard assumptions of consumer theory in microeconomics: A representative agent maximizes utility subject to a budget constraint. We follow Jerry Hausman (1979) and (1985), Dubin et al. (1986), and Dewees and Wilson (1990), and specify utility as a separable function of comfort and consumption of other goods and services.

Let the utility of agent i at time, t, be $U_{it} : \Re_+^2 \rightarrow \Re$, which is defined over consumption C_{it}, and comfort K_{it}.

$$(1) \qquad U_{it} = u(C_{it}, K_{it})$$

The utility function satisfies $u_v(C_{it}, K_{it}) > 0 \ and \ u_{vv}(C_{it}, K_{it}) < 0 \ where \ v \in \{1,2\}$ and the Inada conditions.

Comfort, K, *as in* Hausman (1985; pp-1262) depends on outdoor temperature and adaptation. More specifically, K_{it} depend upon the state of climate θ_{it}, the degree of building insulation h_i, adaptive equipment, A_i (heaters, fans, etc), and electricity use, E_{it}. We allow the efficiency of these complementary inputs, $\mathrm{W_t}$, expressed by “technological change”, to change over time.

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[4] See Masters and McMillan (2001), Gallup et al (1998), and Warner (2002) for more information

[5] Contributions by LeComte and Warren (1981), Suckling and Stackhouse (1983), Dubin (1986), and Kushman and Anderson (1986) are early attempts at investigating the effect of cooling and heating on energy demand. However, these papers suffer at least one of the problems we have mentioned.

(2) $$K_{it} = f(h_i, A_i, \mathrm{W_t}, \theta_{it}, E_{it})$$

An assumption underlying (2) is that insulation and appliances are determined by location and does not change over short periods of time with the variations in weather. However, as we shall see below, our framework allows for differences across location that does not change over time such as geography and for changes over time that are common across locations such as inslating equipments and relevant technological changes. [6]

The main presumption in the literature and in our approach is that comfort increases with temperature at low temperatures but decreases at high temperatures. In cold times/places, an exogenous temperature *increase* reduces demand for heating and thereby frees up resources for consumption of other goods. In warm times/places, it is a temperature *reduction* that frees up resources. Electricity usage for comfort will thus be U-shaped with respect to outdoor temperature: high when it is cold and warm, and lower in the intermediate range. Said differently, a 5 ℃ increase in temperature from negative 3 ℃ has an effect on comfort and electricity consumption opposite to that of a 5 ℃ increase in temperature from 30 ℃.

There are two main approaches in the literature to allow for this nonmonotonicity of the effect of temperature. One approach is to use seasonal or monthly temperatures, and the other – which we follow - uses heating degree days (HDDs) and cooling degree days (CDDs) generated from daily temperature data.[7] The idea behind CDDs and HDDs is that a temperature interval is defined as a comfort zone (this could be what we call 'room temperature', e.g. between 18℃ and 22℃). Within the comfort zone, a household is assumed to have no demand for cooling or heating, while cooling demand occurs at outdoor temperatures below the comfort zone, heating demand above.

For our empirical estimation, we use a constant elasticity of substitution (CES) utility function: $U_{it} = \left[aC_{it}{}^{1-\gamma} + (1-a)K_{it}{}^{1-\gamma}\right]/(1-\gamma)$ where gamma describes the substitutability between consumption and comfort and satisfies $\gamma > 0, and \neq 1$. Also, we assume $a\epsilon(0,1)$). We describe comfort by (2') as a Cobb-Douglas function.

(2') $$K_{it} = h_i \cdot (A_i W_t E_{it})^m \cdot e^{-\alpha_{CDD}} \cdot e^{-\alpha_{HDD}} \quad \text{where,} \, \alpha_j, m \in (0,\infty)\,^{8},$$

According to equation (2'), in the absence of any adaptive measures, comfort reduces to $K_{it} = h_i \cdot e^{-\alpha_{CDD}} \cdot e^{-\alpha_{HDD}}$, which is decreasing in CDD and HDD. Thus, comfort associated with CDD (HDD) of 20 is lower than comfort associated with CDD (HDD) of 10. On a winter day in Northern Europe, HDD of 20 is common, and on a summer day in Southern Europe, CDD of 15 is common.

Equation (2') enables us to allow both cold and warm weather to bring discomfort and thus higher electricity consumption (though not necessarily with the same slope). The parameters α_{CDD} and

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[6] See Freedman (1987) and Dewees and Wilson (1990) on how insulation of housing is related to geography.

[7] The HDD and CDD are calculated with $HDD_{it} = 18 - T_{it}$ and $CDD_{it} = T_{it} - 22$ where T_{it} is the average daily temperature of country "i"at time "t" measured (in Celsius) . The definition of a day's average temperature is standard: for the 24 hour period, the maximum and the minimum temperature is recorded, and the average daily temperature is the midpoint (or mean) between these. HDD and CDD take non-negative values by definition, and for most countries, most years, both HDD and CDD will have a strictly positive value.

[8] $E = \bar{E}$+1 where $\bar{E}$ the true electricity consumption. This approximation keeps comfort from becoming zero when no electricity is consumed.

α_{HDD} measures the sensitivity of comfort with respect to changes in weather and combined with m they measures the productivity of electricity E_{it} in mitigating the negative effect of weather. For a given exogenous increase in weather, E_{it} could increase such as to maintain a constant comfort level. However, since this has a cost, electricity consumption *ceteris paribus* will adapt less than this, so comfort declines despite adaptation.

What remains to specify is the budget constraint. We take C_{it} as the numeraire and assign a fixed income of y_{it} to the agent. Thus, the budget set is given by [9]

(3) $$C_{it} + P_{E_{it}} E_{it} \le y_{it} \text{ .}$$

Maximizing (1) subject to (3), taking into account (2) and designating the shadow price of income by λ provide us the first order conditions that determine the demand functions.

(4) $$U_1(C_{it}, K_{it}) \equiv \lambda$$

(5) $$U_2(C_{it}, K_{it}) \frac{\partial}{\partial E_{it}} K_{it}(\theta_{it}, E_{it}) \equiv \lambda P_{E_{it}}$$

(6) $$C_{it} + P_{E_{it}} E_{it} \equiv y_{it}$$

The conditions in (4) and (5) combined require that the marginal rate of substitution between C_{it} and K_{it} should be equal to their respective costs. Equation (6) implies that no income remains unused. Using the utility function and (2') into (4) and (5), we have:

(7) $$\pi C_{it}^{\gamma} K_{it}^{1-\gamma} \equiv P_{E_{it}} E_{it}$$

Where $\pi = m(1-a)/a$ Using (7) and solving for E_{it} in (2), we obtain equation (8) after some algebraic manipulations.

(8) $$E = (1/\pi)^{1/(m(1-\gamma)-1)} \, (1/\nu)^{(1-\gamma)/(m(1-\gamma)-1)} P_E{}^{1/(m(1-\gamma)-1)} \, \theta^{\alpha_j (1-\gamma)/(m(1-\gamma)-1)} C^{-\gamma/(m(1-\gamma)-1)}$$

Rewriting it in natural logarithms, one arrives at[10]:

(9) $$lnE_{it} = \beta_0 + \beta_P lnP_{E_{it}} + \beta_y lny_{it} + \beta_H HDD_{it} + \beta_C CDD_{it} + \mu_t + \varphi_i + v_{it}$$

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[9] Though equation (3) is standard and simple, it could pose a challenge when it comes to the product electricity. The problem, as noted by Taylor (1975), is that electricity may be sold at a decreasing price blocks. But, Halvorsen (1975) offers a specification where it is possible to estimate the demand function in decreasing price blocks. This problem is irrelevant, as Hausman (1985) notes, if unit prices are increasing over quantity blocks, the budget set remains convex and the properties of demand functions hold . Berndt (1978) indicates that the cost of misspecification in terms of empirical value is practically immaterial and can be ignored.

[10] We employ the approximation that Using the approximation that $\ln(y/P_E E - 1) \cong l\,\mathrm{n}(y/P_E E)$.

Equation (9) provides the fundamental organizing framework for our empirical estimation.[11] It defines the demand for electricity as a function of relative price of electricity, CDD, HDD, income, and the characteristics of housing and appliances. Having estimated (9), the original parameters of the utility function can be recovered as follows.

(9-a) $\beta_0 \equiv \ln \pi^{-1/(m(1-\gamma)-1)}$,

(9-b) $\beta_P \equiv 1/(m(1-\gamma)-1)$,

(9-c) $\beta_y \equiv -\gamma/(m(1-\gamma)-1)$,

(9-d) $\beta_{HDD} \equiv [\alpha_{HDD}(1-\gamma)]/[m(1-\gamma)-1]$

(9-e) $\beta_{CDD} \equiv [\alpha_{CDD}(1-\gamma)]/[m(1-\gamma)-1]$

(9-f) $\mu_t = -m(1-\gamma)/[m(1-\gamma)-1]W_t$

(9-g) $\varphi_i = \{-(1-\gamma)/[m(1-\gamma)-1]\}(\ln h_i + m \ln A_i)$

4 Data Sources and Descriptive Statistics

To estimate the model we collected a detailed and comprehensive panel data set on electricity consumption and climate. Estimation of the model and computation of the impact of climate change require data on per capita household electricity consumption, per unit electricity prices (or tariffs), taxes on electricity consumption, per capita income, and historical heating and cooling degree days. Our study develops and exploits panel data of 12 years for 31 European countries. [12]

4.1 Data Sources

Household consumption of electricity in kilowatt hours (kWh), and price per kWh, are obtained from Eurostat and for some countries from IEA (2007), and EIA (2007). Real per capita income, population size, and the consumer price index (CPI) are obtained from the World Development Indicators.
Cooling and heating degree days are generated based on annual temperature from the NCEP data set (see Benestad, 2008). We chose three large cities in each of the larger countries, and taken the average cooling and heating degree days as representative for the national cooling or heating degree days.[13]
For likely climate impact, we use regionally downscaled values of the IPCC A1b climate scenario using an empirical-statistical downscaling (E-SDS) method, as described in Benestad (2004) and Benestad (2005).[14]

4.2 Summary Statistics

The first panel of Table -1 reports average electricity consumption, electricity prices, and per capita income in Europe between 1994 and 2005. Over the period, electricity consumption varied between

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[11] A number of papers have approached the problem of estimating time series, or cross-sectional, or panel aspect of such an equation. Bigano and Bosello (2006), and De Cian, Lanzi, & Roson (2007) are some recent examples. We describe how we handle the problems of simultaneity, omitted variable bias, and measurement errors in the next sections.

[12] Details of the data sources are reported in annex c.

[13] See Table-5 in the appendices for the list of countries and cities. For small countries with a concentrated population, only the capital city is used.

[14] See Benestad (2008) for the description of the method, data, and results of the E-SDS data used here (using Meehl et al. (2007)).

2900 kWh and 3500 kWh per capita, increasing by roughly 1% per year. The first column of Table -2 presents the same data, averaged over time, in a different dimension. The highest per capita residential consumption of electricity is observed in Norway and the lowest in Romania. Except for Luxembourg, the top-electricity consuming countries are the Nordic countries.

Over the same period, mean per capita income has increased by about 2% per year from 1994 to 2005. The poorest countries in the sample are Bulgaria, with average per capita income of 6351 US$ measured in PPP, followed by Romania and Turkey. The richest countries in the sample are Luxembourg, Norway, and Denmark with average incomes of 48 000, 33 000, and 28 000 US$ respectively. Roughly half of the countries have income greater than or equal to the sample average.

The average electricity tariff has been relatively stable over time. Its value has varied between eight and nine cents per kWh. On average, electricity has been cheaper in Eastern European countries, which also have lower average incomes. Electricity has typically been more expensive per KHW in Italy, Germany, Portugal, and Belgium.

4.3 Climate Variables

Tables 1 and 2 report the average values of HDD and CDD. The average HDD is 2921 while the average CDD is 91. Variations in year–to-year HDD are observed, but CDD values display greater stability. As can be seen from Figure 1, the number of HDD is strongly associated with geographical location of countries, and countries farther from equator have more HDDs and fewer CDDs. Almost all of the countries in the sample have lower CDD compared to HDD.

To portray an image of climate change, we use Benestad (2008), which generates the Empirical-Statistical Down Scaled [E-SDS] values of the IPCC scenario Ab1.[15] The scenario run contains downscaled heating and cooling degree days for Europe at city level. Thus, as with the observed CDD and HDD, the relevant values are for areas where people live, for the reasons mentioned earlier.

Figure 2 plots the annual HDD and CDD for continental Europe from 1900 to 2100 based on SRES scenario Ab1. As can be seen from the graphs, the average HDD decreases sharply over this century, by almost 700 degree days. Similarly, the second panel of figure 2 indicates that the average CDD increases by almost 120 degree days in this century. Even though the rate of change might differ from country to country, the general story is that HDD decreases by larger amount than CDD.

5 Econometric Strategy, Data Analysis and Discussion

The first part of this section describes econometric problems and our strategies. In the second part, we test hypotheses regarding whether climate is an important determinant of electricity demand. We also provide robustness tests for our results. We include a section where we use climate models to portray an image of the impacts of climate change on electricity consumption in Europe under the Ab1 scenario. The last part presents the results of estimating unbiased and consistent price and income elasticities.

5.1 Econometric Problems, and Strategies

It is a well known problem that market prices and demand – quantities – are jointly determined. Thus, prices are not exogenous to consumption and, in principle, it could have a non-zero correlation with the residual term v_{it}, leading to biased estimates of the price elasticity with ordinary least squares

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[15] A1B, the emission scenario used here for illustrative purposes, `A1B is the main emission` scenario for the International Panel of Climate Change projections of continental surface temperature anomalies. (IPCC 2007,WG1, page 75).

(OLS). The trick to resolving this problem lies in recognizing that price has two components, where one component has zero correlation to v_{it} while the other component has a non-zero correlation. By using an exogenous instrumental variable, in this case value added tax per kWh, it is possible to remove the part that correlates with the residual term. The success of this strategy depends upon whether tax per kWh exhibits strong co-variance with prices but is still exogenous.

The next problem we examine is related to the income variable that we use in estimation of the parameters of equation (9).[16] While all the studies that use country level datasets to estimate income elasticity for per capita electricity consumption, there are many problems tied to this variable. The first could be reverse causality; i.e., per capita income of a country may depend on electric energy used. This problem would perhaps be more critical for longer term developments than year by year, and more for industrial electricity demand than residential electricity demand. The other problem with per capita income is that it can potentially be measured with error.

True per capita income is not measured by the traditional per capita income of UN national income accounts for conventional reasons, such as omission of household activities, underground economy, etc. In this case, per capita income could be considered as a proxy for the true income. But there are legitimate reasons to suspect endogeneity, as when electricity use frees up time that can be used to generate income. The strategy we employ to fix this problem is to use as an instrument the economy's total revenue from value added tax. This strategy addresses both the measurement problem and the potential endogeneity problem.

Omissions of variables $\mathrm{CDD_{it}}, \mathrm{HDD_{it}}, \varphi_i,$ and μ_t raise the issue of omitted variable bias, as long as these variables are correlated with unobservable variables in the residual term. For example, if geography is correlated to CDD/HDD (see figure-1) and income (see Masters and McMillan; 2001, Gallup et al; 1998, and Warner; 2002), then omission of CDD/HDD is a serious problem for getting unbiased income elasticity because income could also reflect the impact of CDD/HDD on kWh.

As we introduce time- and state-fixed effects, we also solve potential omitted variable problems. For example, the Norwegian special endowment of hydro-power potential – related to topography and geography – is reasonably fixed over the period in question. It may also be the case that this endowment has had direct impact on personal incomes through the energy-intensive industries of Norway, which have been key drivers in Norwegian economic history. As long as these country-specific fixed effects are correlated to electricity consumption and income, the income elasticity would be biased. We remedy this problem by using detailed panel data on $\mathrm{CDD_{it}}$ and $\mathrm{HDD_{it}}$ along with electricity consumption, prices, income, and employing a panel data technique that purges bias due to unobservable φ_i and μ_t.

Thus, the key assumption in estimating equation (9) after taking care of the state and time-fixed effects is $\mathrm{E}\left[v_{it} \middle| \ln \hat{P}_{E_{it}}, \ln \hat{y}_{it}, \mathrm{CDD_{it}}, \mathrm{HDD_{it}}, \varphi_i, \mu_t\right] = 0$. In a way, the demand for other uses of electricity such as light, hygiene, entertainment, etc. is assumed to have no systematic co-variation with the demand for electricity through heating and cooling. To the extent that the residual term fails to be orthogonal to the right hand side terms, the estimates could be biased. Similarly, time-fixed effects can pick up biases due to shocks that are specific to a given year, invariable across countries.

In sum, it is important to note that a fixed-time trend can pick up movements over the years that are common across countries. Such a trend could be, for instance, a tendency towards higher energy efficiency or smaller households not associated with the movements of the electricity price, income, or climate. Moreover, there could be shocks year-by-year that are common across countries, such as oil price shocks. Hence, our strategies in using instrumental variables and fixed and random effects to estimate parameters are well adapted to estimate a traditional demand function that is not biased from omission of the impacts of climate on electricity demand.

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[16] The Vol 29. Issue 6 of *Energy Economics* has a number of interesting papers that investigate the direction of causality between income and electricity consumption in many countries.

5.2 Estimating the Impact of Climate on Electricity Demand

We want to estimate the effects, if any, of climate on electricity demand and its likely impact under different climate scenarios. Table 3 presents estimates of the importance of climate in residential electricity demand using different estimation techniques.

The ordinary least square results are reported in the first column, while the second column onwards shows effects that control for both state- and time-fixed effects. An additional cooling degree day or heating degree day raises electricity consumption by 0.04% and 0.01 % respectively. The values of the estimates are more or less stable across different estimation techniques (excluding the OLS estimates of the first column).

In most estimation cases considered, both the heating and the cooling degree days are statistically significant at 1% and with a sign in line with a priori assumptions. The next question is whether the estimates are robust. In all cases, the coefficient on CDD is greater than the coefficient on HDD. This has been the case in almost all studies that have attempted to estimate this effect. Among postulated reasons is that there are many heating alternatives (such as wood, gas, etc), while for cooling, electricity is more generally the only option.

An important question here is whether the estimated results regarding cooling and heating degrees are the result a variable that affects both the climate variables and electricity demand. A main candidate could be geography. On the one hand, northern countries are richer and hence consume more electricity; on the other hand, geography is correlated with climate (as shown in figure 1). If this mechanism is important, climate may not affect demand for electricity, and estimates merely illustrate the impact of geography.

In order to test this hypothesis, we collected geographical data, mainly latitude. Hall and Jones (1999) have used the distance from the equator as a measure of geography. In this section we use Hall and Jones's data to test whether our climate variables reflect this extraneous effect.

Table 4 reports the results of demand estimation once the impact of latitude is controlled for. The first column reports the effect of geography on demand without controlling for climate. OLS results in a statistically significant impact of latitude, and this effect persists when climate variables are included. Climate variables remain significant even after controlling for latitude in all the models, even though latitude is insignificant. We can also see that our estimates of the coefficients on the climate variables are robust to this correction in a quantitative sense.

5.3 Estimated Price and Income Elasticities

We start with the OLS results and proceed to our preferred estimates to facilitate comparisons with the literature. The first column of Table 3 reports the fit of equation (11) with the data using the ordinary least square estimation technique. The values under each estimate are robust standard errors. Estimated price and income elasticities have the sign expected a priori.

A price elasticity of 0.5 to 0.6 is in line with the existing estimates in some of the literature that uses OLS (our OLS estimate is 0.53). For instance, Anderson (1973; table 7) and Barnes et.al (1981) obtain price elasticity estimates of 0.58 and 0.55% respectively. Anderson (1973) uses time series data for California for 1947 to 1969, while Barnes et al. (1981) uses household survey data from the USA. Turning to income elasticity estimates, the OLS income elasticity of 1.3 is close to Halvorsen (1975), who used using macroeconomic data from USA.

Estimates based on macro data may be subject to bias for a number of reasons. The obvious reason is that prices are not exogenous to demand. However, the implicit argument behind these results in the literature is that most power plants such as coal, nuclear, and hydro power plants are built to last for long periods such as 40 years or more (or for other reasons have marginal costs – or tariffs – that do not vary with demand).

Though this argument seems plausible, it does not eliminate the endogeneity problem entirely. First, as mentioned before, prices, and also incomes, can pick up the effect of omitted variables such as climate that affect both demand and prices. Hence, obtaining the right signs alone does not grant confidence in the estimates. Second, there are also state-specific and time-specific unobservable variables that may correlate with prices and demand, and result in non-zero co-variance between the explanatory variables and the residual term. In most cases, estimates based on cross sectional or time series data alone are susceptible to such problems. For instance, there could be gains in efficiency from using adaptive equipment that is constant over states but rises over time (as if there is learning by heating or learning by cooling). There could also be important geographical variables such as distance from the equator that influence the climate of the region and at the same time affects electricity prices and demand.

Third, power plants may operate at varying capacity utilization rates and the demand function may not be identified. Nuclear and coal power plants operate at full capacity, and gas-fired power plants are used in peak load situations. Gas prices may vary with general level of economic activity leading to simultaneity bias. We address each of the four problems step-by-step in the following sections.

The first step is to control the climate factors and obtain the estimates. This reduces the estimated price elasticity from 0.53 to just 0.40 while keeping the income elasticity at 1.30. This value of price elasticity is similar to Mansur et al (forthcoming, the second panel of Table 3) who report a price elasticity of 0.39.[17]

The second panel of Table 3 reports the results of estimation of the same parameters using both fixed effects and random effects. The main justification emerges from equation (9), which explicitly demands fixed effects to be controlled for. Controlling for state-fixed effects alone reduces the price elasticity and income elasticity estimates, suggesting that omission of the fixed effects biases both these estimates upwards. The magnitude of these elasticities are roughly similar to Liu (2004; Tables A7 and A9), who obtains a price elasticity of 0.3 and an income elasticity of about 0.4. As a comparison, this is interesting. First, he uses a panel of OECD countries from 1978 to 1999, and a one-step GMM in line with Arellano and Bond (1991). There is geographical similarity in the samples of the two papers, even though both country and years give each sample observations that the other one has not considered.

To deal with the endogeneity problems, we employ instrumental variables. There are two instrumental variables available for the price of electricity, namely final total tax per kWh and value added tax per kWh. Both are exogenous to supply and help us obtain the component of price that does not correlate with the error term. However, the former is a weak instrument while the latter is strong, as measured by the F-statistics in the first stage regressions (Stock and Watson, 2003; PP 350 and PP 370-372). The third column of Table 3 presents estimates obtained when we use value added tax as an instrument for price. The absolute value of the estimated price elasticity now has changed to 0.2, validating the suspicions about bias due to endogeneity.

To correct for the possible correlation between the error term and the per capita income, we use the total value added taxes in the economy. Table 3's fourth column shows the consequence of possible co-variation between income and the residual term in equation (11). Now, both the fixed- and random-effect estimates raise the value of income elasticity, and the gap between the two estimation techniques has narrowed considerably, down to just 5% compared to 30% in simple panel estimation without using instruments.

The last column reports the results of estimation when we employ instruments for both prices and income. Both the price and income elasticities are statistically significant and the distance between the values of estimates in the random-effect and the fixed-effect is even lower than what the earlier estimates suggest. Our concluding estimates are a price elasticity of about -0.2 and an income elasticity of about 0.8 for residential electricity demand.[18]

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[17] Even though it would be interesting to compare their estimates, we do not do so because the two papers employ different measures of climate, and Mansur et al. (2008) do not estimate income elasticity.

[18] This result is quite close to evidence based on detailed micro level data for China by Asadoorian et.al (2007). See their Table 6 for comparison.

As a test of robustness, we reestimated the parameters of the demand function including the price of other fuels such as gas using Eurostat data (this reduces the size of the sample quite considerably). While the price of gas is statistically insignificant, the magnitude of the other parameters remained more or less unchanged. We do not report this results here, but they are available upon request.

5.4 The Impact of Climate Change on Electricity Demand in Europe

The econometric result of per capita electricity consumption on price, income, and indicators of climate can be used to map the impact of climate change on electricity consumption. Projecting electricity demand for the century, until 2100 would require a number of strong assumptions, and it needs to be underlined that we are not forecasting. Rather, we limit our effort to use a climate scenario for this century to illustrate the effect of climate change on electricity demand on the present economy, ceteris paribus.

The message from figure 2 suggests that the demand for electricity is going to be lower in the coming century. According to the results from observed year-to-year HDD and CDD variations on the logarithm of electricity consumption, a unit change in HDD has 0.0001 changes in electricity consumption, while a unit change in CDD has an impact four times greater (table 3). That is, if other things remain constant, mapping the current economic environment on future climate under scenario Ab1 results in a demand for energy illustrated by figure 3.

Figure 3 plots the sum of the two effects through predicted per capita residential energy demand for Europe of climate change portrayed for this century in IPCC's scenario Ab1. Given the cost Europe is incurring for heating buildings in the residential and service sectors, the message from the figure above is that Europe as a whole and in net – through electricity demand for heating and cooling – is going to benefit from climate change over the coming century. However, some countries – in the North – whose cost of heating is high and cost of cooling is low will benefit more, while others, in the South, will benefit less, or lose.

These effects through electricity demand for cooling and heating may not be the most important effects of climate change, and even for these, the reductions in demand in winter in the north and the increases in demand in the summer in the south may be as important, or more, than the net effects in demand when summed over the seasons and over the years. This more detailed use of our estimates, however, we leave to future research.

6 Interpretation

Once a climate-adjusted demand function is estimated with a reasonable degree of precision, it is important to ask what the estimates mean to problems in policy and decision makings. There are many policies related to the electricity demand. In this section, however, we provide a brief overview on the implication of the results for three major important policy problems related to climate change, namely effectiveness of mitigation policies, the implication of economic development, the implication for adaptation policies.

It is emphasized from the beginning of this paper that a successful mitigation policy stimulates agents to change their consumption and production behavior. For example, the European Union has decided to unconditionally reduce GHG emissions by 20% in 2020, and the electricity sector is expected to play the biggest role in this respect. See Eskeland, Rive, and Mideksa (2008) for quantitative aspect of the role of electricity sector in EU's 20% abatement in a general equilibrium framework.

This policy may demand that electricity consumption is reduced, in a combination of policies that also reduces the carbon intensity of electricity production (raising the share of natural gas and wind, say). This is achieved in part by introducing emission quotas, which in turn to some extent will raise the relative price of electricity. The role that demand reduction plays in the overall solution, if pursued cost effectively, depends on parameters such as the income elasticity, the price elasticity, and the climate sensitivity of electricity consumption, alongside with the costs of producing electricity with less GHG emissions[19].

In our central results, the price elasticity is estimated to about -0.2, meaning that a doubling of the electricity price (from 10 eurocents to 20) would be required if the price alone were to institute an emission reduction of 20%. In reality, reduced consumption due to price effects will work together with reduced GHG content of electricity production, and income-related demand growth will also need to be factored in[20]. Two elements are remaining, and both are in our research agenda. One is to develop the welfare costs of climate change with and without adaptation in a partial equilibrium framework. The second is to integrate the estimated climate change adaptation equations in a computable general equilibrium framework for integrated assessment.

The estimated value of income elasticity is relevant for many of the considerations of climate change policies. The value of the income elasticity of 0.8 suggests that electricity is a normal good, and a necessity rather than a luxury good. That means that if income increases continuously, the consumption of electricity increases at a somewhat lower rate. If income per capita in Europe grows at 2% on average, this leads to an increased electricity consumption by 1.6% per year. If, in the years ahead, prices increase, programs for energy efficiency are pursued and there is also technological innovation, consumption of electricity may well increase at lower rates, or even fall. At the same time, however, chances are that the use of electricity will expand to additional applications, perhaps due to GHG abatement policies. Should it be the case, for instance, that electricity makes big advances into transport (rail, plug-in hybrids), electricity production in cleaner forms may have to expand. The observation that the long term of a century – required to have important changes in HDD and CDD – will involve big changes in technology, economic structure, etc., is motivating us in choosing not to simulate an exposure of our future economy to a projected future climate scenario.

The important message from the estimates is relevant for producers, consumers and policy makers alike: Global warming is likely to reduce the heating demand but increase the cooling demand, and our best estimate is that an increase of one cooling degree day per raises annual household electricity consumption by 0.04% while a decrease of one heating degree day reduces demand for electricity by just 0.01%.

7 Summary and Conclusions

In 2003, the heat wave in Europe took a large number of lives. Mainly the old and the sick were severely affected. During the 2005 heat wave, there were far fewer fatalities. This was in part due to its lower intensity, but may also have been in part due to the greater alertness and preparedness created two years earlier. [21] We take this to indicate both that the temperature aspects of climate change are noteworthy, and that adaptation – including through heating and cooling – can be equally if not more important and should be part of our advance thinking on adaptation.

By developing a comprehensive panel data set from Europe and employing suitable econometric estimation techniques, this paper tested the impact of climate variables on electricity demand. It reports a temperature adjusted demand system for electricity using the concepts of cooling degree days (CDDs) and heating degree days (HDDs), and offers unbiased estimates for price and income elasticity.

The coefficients of temperature, measured in both cooling degree days and heating degree days, have been statistically significant in all cases and robust to alternative tests. In all cases, the marginal

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[19] There are many indications that supplementary policies, such as support for renewable, will shave at least part of the price increase that would be efficient both for electricity and emissions, thus making more difficult the mitigation challenge for Europe.

[20] Eskeland (1994) shows how demand parameters determine the optimal role of demand reduction in a pollution control program when there are also possibilities for reducing the emission intensity of the product.

[21] Bigano(2006)

impacts are estimated to be stable, and that the marginal impact of CDDs is greater than that of HDDs. Problems associated with omitted variable bias, simultaneity, and measurement error often seen in the literature have been addressed by the use of instrumental variables for price, income, and controlling for omitted variables. The results of the estimation suggest that electricity is a normal good – not a luxury good – in a European context. Consistent with the income elasticity, the price elasticity is below one, i.e. quite inelastic.

Our results are based on macro-level data. It exploits a panel for all it is worth, but the results should also be seen in the light of limitations associated with our intention to obtain results for Europe as a whole. To attain consumption data (kwh) and tariff data for households and services (i.e. not including manufacturing, nor exports) it is necessary to work with annual and country level data. This means that one is willing to accept certain homogeneity assumptions, to exploit part of the variation in the data that exists between countries, and a part of the variation between the years. Two alternative research directions obviously are both important: one is to work with a finer time resolution for consumption data (by month, for instance), another is to work with a finer spatial resolution, either in terms of regions (regions of Norway, for instance) or to work directly with micro-level data (individual households, for instance). Both of these directions are represented in the literature and should be seen as valuable supplements to our approach, but both would fail to give answers at a European level, which was our goal. Estimates based on household-level micro-data can take into account the problems we have considered. Among our aims is to conduct one or a few such studies, place it in a relevant literature context, and use comparison between these two approaches to gain additional insight into the questions motivating our inquiry. It is the case that there are a number of careful studies that have tried to resolve some of the above problems, but to the best of our knowledge there is no study that uses up-to-date micro level data and techniques to tackle the three challenges of concern. It is clearly important to make progress with regard to the evidence based on micro-level data.

Moreover, this study has provided the magnitude of parameters that are relevant in the formulation of climate policies and in debates about the link between economic development and the electricity sector. However, it is important to note the limitations of our exercise. Like all empirical exercises, the central assumption behind working with the empirical models is stable behavioral relationships. This specifically means that the coefficients of the empirical demand model remain the same before and after climate change. We believe it is important to be modest in interpreting the relevance of results like the present ones, in particular when addressing the difficult task of thinking about change in Europe over several decades. In the course of several decades – or a century – Europe will experience not only climate change (in terms of changing numbers of HDDs and CDDs), but also income change and changes in electricity prices. There will be changes in urban structure and how we live, in technology etc. It may very well be, for instance, that changes in household size (share of people living alone), wealth, and the energy efficiency of buildings will induce changes in electricity use far more important than those indicated by climate change based on the variation in our data set of 31 European countries over about 10 years. In part for the reasons of these complications, in order not to convey a false sense of ‘precision’, we have been very brief and simplistic in our ‘effect of climate change’ simulations: not including neither income change or price changes, simply the partial effects of the climate change as if present households were to experienced it.

With this reservation in mind, the results in this paper suggest that climate change is more likely to shift the demand for electricity upwards in the south in the summer, downwards in the North in the winter, and with both upward and downward changes in central parts of Europe. The net effect is certainly uncertain and perhaps not the most relevant either. Increased cooling demand and reduced heating demand will have predictable implications in terms of changing seasonal needs, the balance between peak-load and base-load capacity and the value of north-south transmission. Were it only for climate change, perhaps we should build houses with better insulation in the south and less insulation in the north than is presently the case. But if we take into account that we are getting richer and more capital-intensive and that saving energy is increasingly valuable, we are likely to build more for energy efficiency in the north as well.

In concluding, we should not fail to emphasize that the climate change impacts and adaptation through cooling and heating demand are only a part of the climate change impacts (and adaptation options) in Europe. The present study does not provide any information on whether this is a major part of climate change impacts and adaptation, though we certainly think other effects are more noteworthy. Nevertheless, as analysts, we report that these effects are statistically significant and quantifiable. As such, they can be discussed, evaluated, and used in integrated assessments.

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World Development Indicators

World Economic Outlook

9 APPENDICES

9.1 Annex 1: Tables

TABLE 1: Summary Statistics over Time

Year	**1994**		**1998**		**2000**		**2002**		**2004**		**2005**		**Total**	
Statistics	**Mean**	**Stand. Err.**	**Mean**	**Stand. Err.**	**Mean**	**Stand. Err.**	**Mean**	**Stand. Err.**	**Mean**	**Stand. Err.**	**Mean**	**Stand. Err.**	**Mean**	**Stand. Err.**
Electricity Consumption(kWh percapita)	2908.68	428.53	3149.71	429.77	3250.42	418.90	3421.97	436.56	3522.16	406.36	3586.55	418.92	3244.17	121.32
Real Income Percapita(2000$ PPP)	16721.34	1540.65	18952.00	1679.22	20376.87	1851.18	21185.67	1871.78	22206.73	1888.27	22813.99	1905.05	19780.52	508.45
Price of Electricity(Euro perkWh)	NA	NA	0.08	0.01	0.08	0.01	0.09	0.00	0.09	0.00	0.09	0.00	0.09	0.00
Cooling Degree Days	128.37	31.59	97.54	28.58	96.14	27.43	85.70	24.84	79.95	25.68	81.66	24.30	90.98	7.63
Heating Degree Days	2887.76	223.34	2940.39	215.91	2711.45	188.87	2759.15	206.88	2922.66	203.40	2934.77	200.88	2920.75	60.54
Total Tax per kWh	0.02	0.01	0.02	0.01	0.02	0.01	0.03	0.01	0.03	0.01	0.03	0.01	0.03	0.00
Value Added Tax Per kWh	0.01	0.00	0.01	0.00	0.01	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.02	0.00
Value Added Tax Revenue(Millions of Euro)	36619.12	12924.15	21765.95	6643.79	23402.26	7007.67	23947.64	6914.66	26360.89	7420.47	27024.98	7409.95	23342.66	2007.19

TABLE 2a: Summary Statistics across Countries

Countries	Q_PCAP	Y_PCappp	P_ELE	CDD	HDD	tax_elc	vat_elc	Agg_VAT
Austria	3364	27427	0.0985	64	2990	0.0352	0.0219	16525
Belgium	3488	26784	0.1169	16	2745	0.0272	0.0250	17085
Bulgaria	1885	6351	0.0512	62	3257	0.0104	0.0104	1732
Croatia	1877	9280	NA	62	2719	0.0149	0.0149	NA
Cyprus	3557	18619	0.0855	553	578	0.0112	0.0130	678
Czech Republic	2756	15621	0.0544	26	3509	0.0132	0.0132	4381
Denmark	4141	27999	0.0771	20	3200	0.1160	0.0382	16632
Estonia	2257	9607	0.0533	5	4452	0.0097	0.0103	549
Finland	6328	24997	0.0712	4	4681	0.0226	0.0170	10381
France	3909	26320	0.0945	60	2014	0.0274	0.0181	104245
Germany	3025	25070	0.1259	22	3370	0.0326	0.0216	132587
Greece	2612	17151	0.0609	387	1086	0.0075	0.0075	9918
Hungary	1939	12846	0.0616	78	3008	0.0090	0.0090	4634
Iceland	5650	27987	NA	0	4777	NA	NA	873
Ireland	3216	27087	0.0889	0	2767	0.0125	0.0112	7529
Italy	2178	25092	0.1481	141	1821	0.0519	0.0183	68699
Latvia	1265	8126	0.0595	15	3942	0.0111	0.0111	594
Lithuania	1159	9108	0.0572	17	4287	0.0103	0.0103	909
Luxembourg	4311	47898	0.1120	31	2818	0.0100	0.0069	1186
Malta	2647	16328	0.0600	308	523	0.0008	0.0008	246
Netherlands	3358	28564	0.0934	6	2952	0.0480	0.0215	29018
Norway	12672	33351	0.0848	1	4526	0.0323	0.0227	14842
Poland	1260	10282	0.0688	29	3587	0.0203	0.0175	12510
Portugal	2076	17722	0.1250	58	1036	0.0065	0.0062	9382
Romania	545	6504	0.0560	61	3317	0.0138	0.0138	4115
Slovakia	2170	11500	0.0569	31	3503	0.0205	0.0205	1716
Slovenia	2488	16355	0.0826	31	2974	0.0125	0.0090	1973
Spain	2421	21140	0.0959	261	1267	0.0186	0.0157	38076
Sweden	7866	25605	0.0703	1	3924	0.0413	0.0230	21657
Turkey	690	6357	0.0885	470	1969	NA	NA	NA
United Kingdom	3459	26119	0.09575	0	2946	0.0054	0.0054	92979
Total	3244	19781	0.08687	91	2921	0.0253	0.0154	23343

Table 2b: Changes in CDD and HDD in this Century under climate scenario of A1

Countries	**CDD_Before**	**CDD_After**	**HDD_Before**	**HDD_After**
Austria	113	214	3032	2181
Belgium	37	89	2849	2032
Bulgaria	112	226	3070	2206
Croatia	110	224	2870	2029
Cyprus	432	584	731	500
Czech Republic	67	144	3515	2600
Denmark	9	23	3234	2543
Estonia	5	14	4128	3215
Finland	1	1	4601	3654
France	66	163	2300	1582
Germany	56	133	3022	2150
Greece	605	916	1224	852
Hungary	150	293	2995	2176
Iceland	0	0	5016	4491
Ireland	0	0	2883	2244
Italy	199	397	1801	1293
Latvia	21	53	4132	3181
Lithuania	45	102	4194	3163
Luxembourg	67	149	2905	2001
Malta	374	568	557	357
Netherlands	12	34	2978	2192
Norway	6	15	4262	3519
Poland	73	160	3532	2588
Portugal	98	211	1113	566
Romania	119	252	2806	2129
Slovakia	120	227	3094	2241
Slovenia	77	157	3010	2192
Spain	346	593	1372	829
Sweden	8	18	3904	3081
Turkey	354	597	2089	1544
UK	2	4	2734	2010
Europe	138	259	2570	1858

Table 3: Regression of Demand for Electricity under alternative Estimation Techniques.

	OLS		Panel		Panel with Price IV		Panel with Income IV		Panel with Price and Income IVs	
			FE	RE	FE	FE	FE	RE	FE	RE
Constant	-5.87465	-6.34738	4.16692	1.41513	2.76657	0.04364	-0.04087	-0.59761	-0.84951	-1.26554
	(0.70375)	(0.71279)	(0..92757)	(0.66686)	(1.06730)	(0.84820)	(1.42964)	(1.31126)	(1.53189)	(1.40896)
Price	-0.53490	-0.39610	-0..07268	-0.07905	-0.21586	-0.19492	-0.07999	-0.08178	-0.18097	-0.16593
	(0.06692)	(0.06217)	(0..02602)	(0.01886)	(0.05540)	(0.05629)	(0.01572)	(0.01617)	(0.04756)	(0.04789)
Income	1.25666	1,27962	0..32738	0.60159	0.44474	0.71651	0.75682	0.80883	0.81626	0.85661
	(0.06162)	(0.06194)	(0.09312)	(0.06691)	(0.10459)	(0.08218)	(0.14389)	(0.13289)	(0.15274)	(0.14153)
CDD		0.00115	0.00038	0.00038	0.00036	0.00042	0.00048	0.00050	0.00040	0.00044
		(0.00019)	(0.00011)	(0.00013)	(0.00015)	(0.00014)	(0.00013)	(0.00013)	(0.00015)	(0.00014)
HDD		0.00020	0.00009	0.00010	0.00007	0.00009	0.00010	0.00010	0.00009	0.00010
		(0.00003)	(0.00002)	(0.00002)	(0.00003)	(0.00002)	(0.00002)	(0.00002)	(0.00003)	(0.00002)
Trend	0.00807	0.00056	0.01619	0.00905	0.01599	0.00828	0.00482	0.00347	0.00600	0.00448
	(0.00575)	(0.00549)	(0.00271)	(0.00241)	(0.00321)	(0.00267)	(0.00393)	(0.00361)	(0.00424)	(0.00384)
N.Obs	265	265	265	265	226	226	250	250	222	222
R^2-within			0.66	0.65	0.52	0.59	0.63	0.63	0.55	0.60
R^2-Between			0.71	0.77	0.69	0.74	0.72	0.72	0.73	0.72
R^2-Overall	0.75	0.80	0.69	0.77	0.65	0.68	0.70	0.70	0.67	0.66

Table 4: Robustness Test of Climate

VARIABLES	OLS-1	OLS-2	RE	RE-IV	RE-IV
Latitude	0.0166	0.0214	0.01405	0.01336	0.00770
	(0.0034)	(0.0065)	(0.01033)	(0.01121)	(0.01047)
y_ppp	1.1244	1.1837	0.56769	0.86024	0.84273
	(0.0598)	(0.0661)	(0.06695)	(0.16027)	(0.14539)
P	-0.4366	-0.3793	-0.07785	-0.20582	-0.17085
	(0.0567)	(0.0589)	(0.01902)	(0.05041)	(0.04713)
trend	0.0065	0.0006	0.00959	0.00518	0.00484
	(0.0055)	(0.0054)	(0.00239)	(0.00436)	(0.00392)
CDD		0.0012	0.00043		0.00045
		(0.0002)	(0.00013)		(0.00014)
HDD		0.0001	0.00009		0.00009
		(0.0000)	(0.00002)		(0.00003)
_cons	-5.1107	-6.1052	1.09429	-1.74801	-1.49955
	(0.6263)	(0.6879)	(0.79271)	(1.57744)	(1.40358)
Obs	265	265	265	222	222
R2 -within			0.65	0.52	0.60
R2-Between			0.70	0.67	0.71
R2-Overall	0.77	0.81	0.75	0.64	0.69

Table 5: List of Countries and Cities Considered in this Research

	Country	City/Cities		Country	City/Cities		Country	City/Cities		Country	City/Cities
1	Austria	Vienna	11	Germany	Berlin	19	Luxembourg	Luxembourg	25	Romania	Iasi
2	Belgium	Brussels	11	Germany	Stuttgart	20	Malta	Birkirkara	26	Slovakia	Bratislava
2	Belgium	Antwerp	11	Germany	Dusseldorf	21	Netherlands	Amsterdam	27	Slovenia	Ljubljana
2	Belgium	Charleroi	12	Greece	Athens	21	Netherlands	Rotterdam	28	Spain	Madrid
3	Bulgaria	Sofia	12	Greece	Thesaloniki	21	Netherlands	Groningen	28	Spain	Barcelona
4	Croatia	Zagreb	12	Greece	Iraklio	22	Norway	Oslo	28	Spain	Valencia
5	Cyprus	Nicosia	13	Hungary	Budapest	22	Norway	Bergen	29	Sweden	Stockholm
6	Czech R.	Prague	13	Hungary	Debrecen	22	Norway	Trondhiem	29	Sweden	Gothenburg
6	Czech R.	Brno	13	Hungary	Gyor	23	Poland	Warsaw	29	Sweden	Uppsala
6	Czech R.	Ostrava	14	Iceland	Reykjavik	23	Poland	Katowice	30	Turkey	Istanbul
7	Denmark	Copenhagen	15	Ireland	Dublin	23	Poland	Poznań	30	Turkey	Ankara
8	Estonia	Tallinn	16	Italy	Rome	24	Portugal	Lisbon	30	Turkey	Adana
9	Finland	Helsinki	16	Italy	Milan	24	Portugal	Sintra	31	U. K.	London
10	France	Paris	16	Italy	Naples	24	Portugal	Braga	31	U. K.	Liverpool
10	France	Marseille	17	Latvia	Riga	25	Romania	Bucharest	31	U. K.	Glasgow
10	France	Nantes	18	Lithuania	Vilnius	25	Romania	Constanta			

9.2 Annex 2: Graphs

Figure 1: Average Observed Climate Indicators and Latitude- Europe

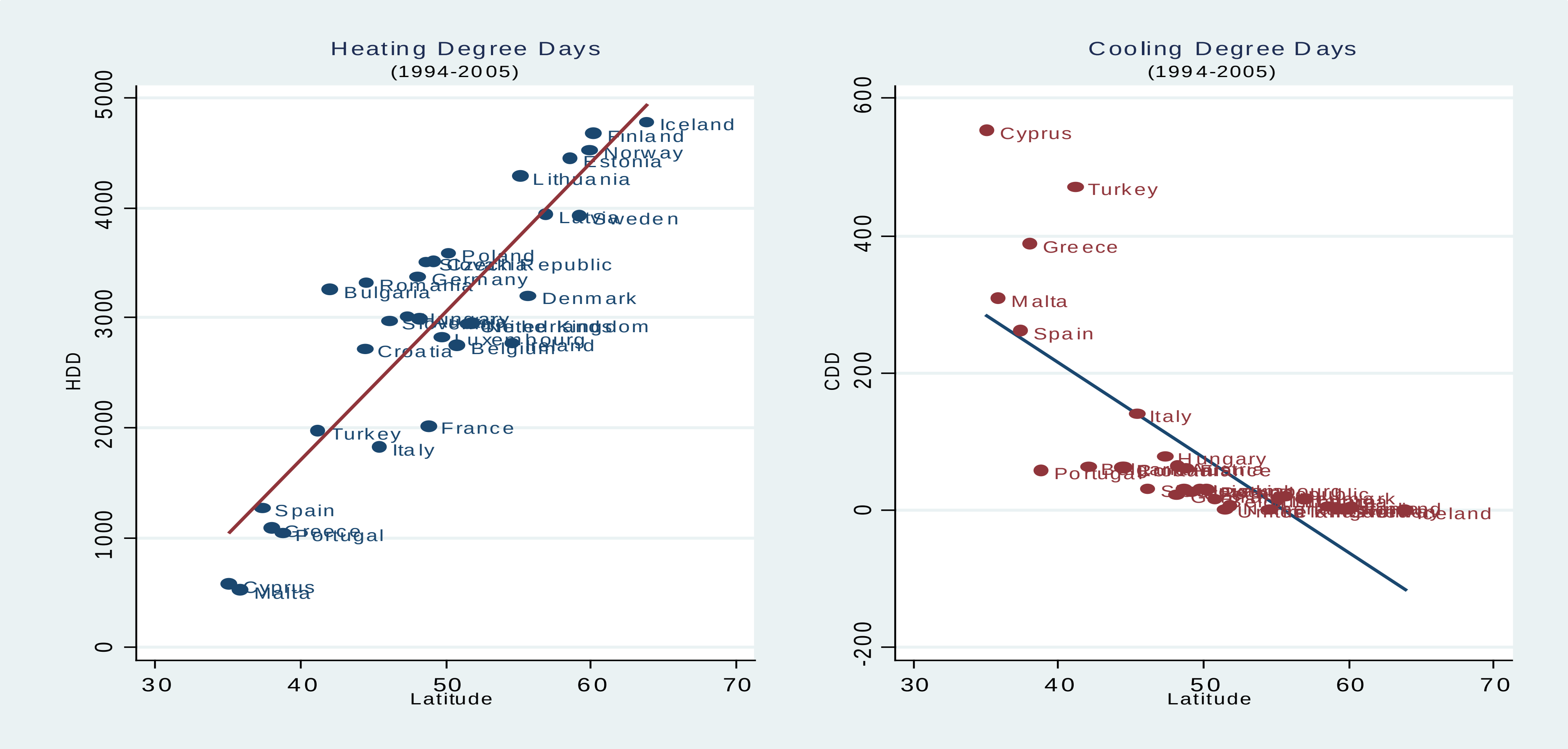


Figure 2: Annual Heating and Cooling Degree Days for Europe under Scenario Ab1

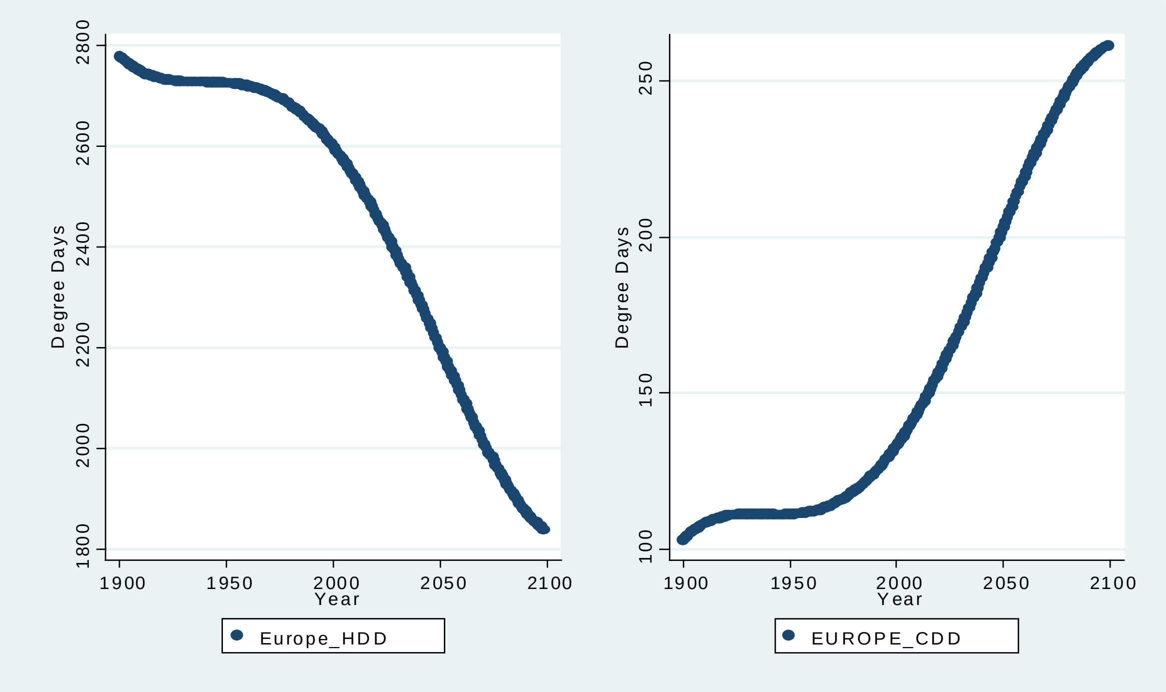
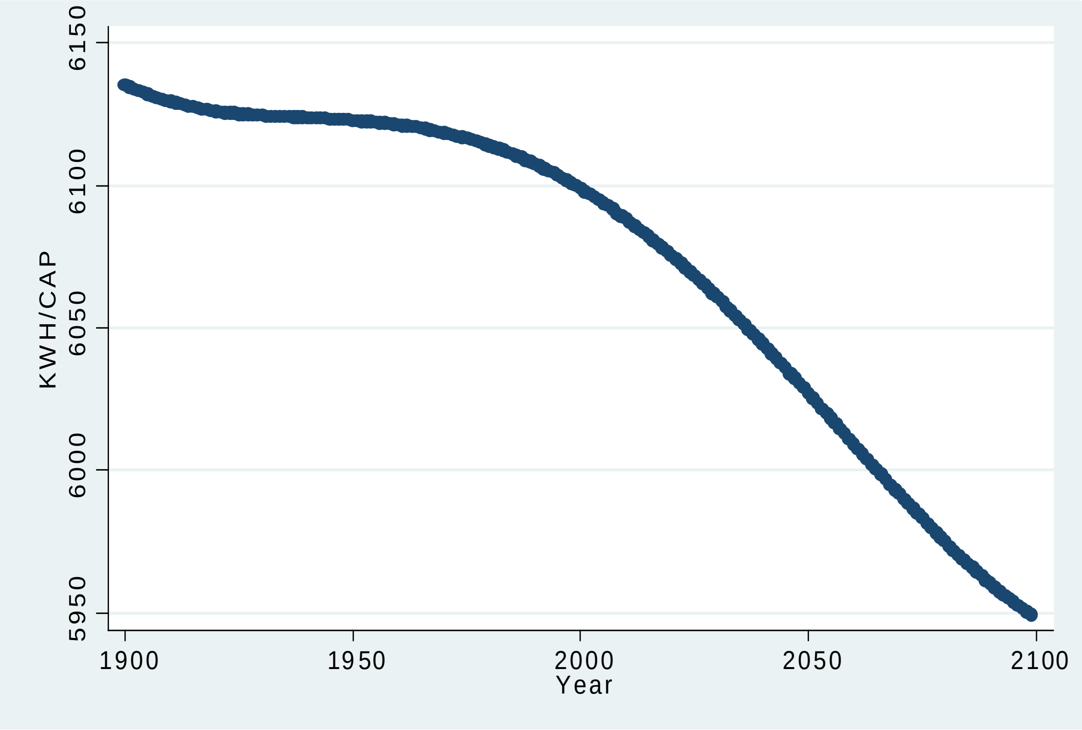


Figure 3: The Impact of Climate Change on Electricity Consumption in Europe



9.3 Annex 3: Data Sources

Residential Electricity Consumption. --- The residential consumption data is collected from Eurostat which has five different series of consumption data measured in units of Watt Hour. The annual data are for standard dwelling of $50m^2$, $70m^2$, $90m^2$, $100m^2$, and $120\ m^2$ each on average having annual consumption of 600 kWh, 1200 kWh, 3500 kWh(of which 1300 kWh is overnight), 7500kWh (of which 2500kWh kWh is overnight), and 20 000 kWh(of which 15 000 kWh is overnight) respectively. The Eurostat presents a standard of annual consumption of 3500 kWh represents the central sample for residential consumption and, hence, we use this series which ranges from 1994 to 2005 for almost all European countries.

Residential Electricity prices and taxes.--- Eurostat reports the electricity prices that refer to domestic households with annual consumption of 3500 kWh (of which 1300 kWh is overnight) associated with standard dwelling of $90m^2$. This data is available in three series: electricity price (Euro per kWh) without taxes, without value added tax but all taxes, and with all taxes. Thus, the value added taxes per kWh and electricity consumption taxes per kWh are generated from the three series. Each of the data is also available as annual average and two half year series.

The Eurostat price series for 1994 are missing for all countries. Other years that are missing for specific countries are as follows: Bulgaria (1994-2003), Croatia (1994-2005), Cyprus (1994-1998), Czech Republic (1994-1998), Denmark (1994-1995), Estonia (1994-2001), Iceland (1994-2005), Latvia (1994-2003), Lithuania (1994-2003), Norway (1995), Poland (1994-2000), Romania (1994-2004), Slovakia (1994-1997), Slovenia (1994-1995), Sweden (1995-1996), Turkey (1994-1997), and the United Kingdom (1994-1995). On the other hand, the EIA has some of the missing prices in kWh per US Dollar basis for Czech Republic (1998-1999) Poland (1998-2000) and Romania (1998-2005). We use Euro US Dollar exchange rate from Eurostat to convert the prices into Euro per kWh. Moreover, the IEA (2002) and IEA (2007) have some the prices that are missing. IEA (2002) provides the 1995 data for Czech Republic, Denmark, Hungary, Norway, Poland, Slovakia, Sweden, and the United Kingdom in Local Currency.

Real Percapita Income. --- The real per capita income is collected in two versions from the World Development Indicators. For each European country, a panel of real per capita income adjusted for purchasing power parity, and market exchange rate based real per capita income ranging from 1994 to 2005 is collected22.

Consumer price index and population size. --- The consumer price index is collected from the world development indicators, and the population data is from the latest IMF's World Economic Outlook for October 2007.

The heating and cooling degrees are calculated based on annual temperature data from USA's NCEP (National Center for Environmental Predictions) data set. The average temperature of a country encompasses areas not only where people reside but also large areas of mountains, rivers, etc that have nothing to do with cooling and heating residences. In order to overcome this problem, we first selected countries with population less than 10 million and took the temperature in the capital city (often the largest city) as representative of the country's temperature relevant for its heating and cooling demand for residential houses. For countries with populations greater than 10 million, we have chosen the three largest cities, and took the average cooling and heating degree days as a representative of the national cooling or heating degree days. See table 5 for the list of countries and cities we have chosen.

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[22] The World Development Indicator lacks data for Cyprus in 2005. We fill the missing data for 2005 using the average growth rate from 1994 to 2004.