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# Do people adapt to climate change? Evidence from the industrialized countries

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## Abstract

**Purpose** – This study aims to explore the link between mortality and climate change. The focus is in particular on individuals' adaptation to temperature changes. The authors analyze the relationship between climatic change (measured by temperature rate) and mortality in 23 Organisation for Economic Co-operation and Development countries during 1970-2010.

**Design/methodology/approach** – This study performs the adaptation regression model in the level form as a dynamic panel fixed effects model. The authors use a non-linear threshold estimation approach to examine the extreme temperature changes effect on the temperature–mortality relation. More specifically, the study explores whether the large increases/decreases in temperature rates affect mortality rates more than the modest changes.

**Findings** – This study indicates that the temperature–mortality relation is significant in early part of the sample period (before 1990) but insignificant during the second part (after 1990). After including controlling factors, as well as nation and year fixed effects, the authors provide evidence that people do adapt to the most of the temperature-related mortalities. Also, this study provides evidence of the non-linear relationship between national temperatures and mortality rates. It is observed that only after 5 per cent increase in the annual temperature, the relation between temperature and overall mortality is significant.

**Originality/value** – Most studies cover only one specific country, hence making it difficult to generalize across countries. Therefore, the authors argue that the best estimation of the health effects of temperature change can be found by modeling the past relationships between temperature and mortality across countries for a relatively long period. To the authors' knowledge, previous studies have not systemically tested the adaptation effect across countries.

**Keywords** Mortality, Climate change, Temperature, Adaptation, Fixed effect model

**Paper type** Research paper

## 1. Introduction

The global climate has changed and will continue do so for decades. In its most recent estimate, the United Nations' Intergovernmental Panel on Climate Change found that the average global temperature has increased by 0.6°C (±0.2°C) since the mid-nineteenth century, and most of this increase has occurred since after the 1970s (IPCC, 2014). Humidity and precipitation levels have also risen markedly, in recent decades, all over the world. Further, it is evident that climate change will have a wide range of impacts on human life and health now and, especially in the future.

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A vast literature documents the excess mortality that has occurred because of the extreme temperatures that cause heat waves (Tol, 2002; McMichael *et al.*, 2006; Haines *et al.*, 2006). For example, Hübler *et al.* (2008) notes that in the summer of 2003, there were approximately 25,000-35,000 deaths due to long periods of intensive heat. Hajat *et al.* (2014) estimate that temperature-related deaths among UK residents will increase by 250 per cent during this century. The World Health Organization estimates that between 2030 and 2050, climate change will cause approximately 250,000 additional deaths per year (WHO, 2014). Watkiss and Hunt (2012) estimated that the welfare costs of temperature-induced mortality, from 2071 to 2100 will be up to €100bn annually. In some parts of the world, however, global warming may also decrease mortality because of more favorable temperature environments that will arise. Bosello *et al.* (2006) predicted that global warming will save more than 800,000 lives, annually, by 2050 (Ackerman and Stanton, 2008).

The aim of this study is to examine how climatic change (as measured by rising temperatures) has affected human mortality in 23 developed countries for the period from 1970 to 2010. Although previous studies have already presented some evidence of these effects, we argue that many of these studies have overestimated the effects of climate change on mortality. Further, to our knowledge, previous studies have not systemically tested the adaptation effect across countries. The main caveat in these studies has been that the estimates are derived from short-term analyzes, which do not fully control for the ability of humans and societies to adapt their behavior to climatic change. Factors such technological innovations and individual and community wealth will influence the association between climate change and health effects (Deschenes, 2014). Also, most earlier studies cover only one specific country, hence making it difficult to generalize across countries. Therefore, we argue that the best estimation of the health effects of temperature change comes from modeling the past relationship between temperature and mortality, across countries, for a relatively long period of time.

We base our analysis on the Becker–Grossman type of health production model (Grossman, 2000). Our analysis proceeds through three stages. First, we construct a fixed-effects panel regression model to explore the short-run relationship between mortality rates and temperature changes across countries. The main advantage of using panel-data models is that we can control for many potential confounding factors.

This study provides evidence of the positive relationship between temperature increases and overall increases in mortality in developed countries during the period of 1970-2010. When the adaptation effect is taken into account, however, only a weak positive relationship between temperature changes and total mortality rates is observed. The adaptation effect is explored using two different sample periods. We perform panel-data analysis for the sample periods of 1970-1989 and 1990-2010. The main findings of this approach are that in the first sample period, the overall mortality rate and some cause-specific mortality rates are related with temperature, but in the second sample period, this relationship almost completely vanishes. Here, our findings support the result of Deschenes and Moretti (2009) and Barreca *et al.* (2016) for the US data on the importance of adaptation effects on the temperature–mortality relationship.

We further examine whether the adaptation effects differ between areas where temperatures differ. To explore this data, we divided the countries studied into three different temperature zones: hot, medium-hot and cold. We noted that the adaptation effect seems to exist, in particular, in those countries where the annual average temperature is below 13°C (medium-hot zone). In our data set for the period after 1990, the temperature–mortality relationship completely vanishes in the cold zone (annual average temperature is below 5°C). In countries in the hot zone, where the average annual temperature is above 13°C, the temperature–mortality relationship weakens but is still significant for some cause-specific mortality rates.

Second, we construct an adaptation regression model in the level form as a dynamic panel fixed-effects model. This approach takes into account the lagged effects of temperatures on mortality rate level. The results of this approach confirm our initial findings of the significant adaptation effect with respect to the impact of temperature changes on most of the cause-specific mortality rates.

Third, we use a non-linear threshold estimation approach to examine the effect of extreme temperature changes on the relationship between temperature and mortality. More specifically, we explore whether the large increases/decreases in temperature affect mortality rates more than modest temperature changes do. Our results indicate that for the period from 1970 to 2010, only a 5 per cent or higher increase in the annual average temperature resulted in significant increases in mortality rates across developed countries. We could not find similar threshold temperature change effects for areas with negative annual temperature changes. We also find threshold temperature change effects for some cause-specific mortality rates. In particular, circulatory specific mortalities seem to increase even after a modest increase in the average annual temperature. Also, respiratory-specific mortalities seem to increase when the average annual temperature decreases by 2 per cent or more.

This paper is structured as follows. Section 2 presents the study’s theoretical framework, and Section 3 gives the empirical specifications and presents the data. Section 4 gives the results of the short-run and long-run panel fixed-effects models. Section 5 presents some concluding remarks.

## 2. Theoretical context

There is a growing literature on the relationship between climate change, adaptation and mortality (Kinney *et al.*, 2008). Adaptation is defined as human adjustment in response to climate change and its effects. Deschenes (2014, p. 606) states that “[. . .] adaptation will refer to the set of actions that are taken in order to reduce the health impacts of exposure to extreme weather events or changes in climate”. Barreca *et al.* (2016) note that access to health care, electricity and residential air conditioning are the three most important twentieth-century innovations that have affected the temperature–mortality relationship. Also, climate engineering, which means the deliberate manipulation of the Earth’s climate, might affect global temperatures in the twenty-first century (Barreca, 2012).

To explore the long-run relationship between temperature and mortality and the adaptation effect, we use the Becker–Grossman model of health production (Grossman, 2000). We also closely follow Deschenes and Greenstone (2011). We suppose that individuals derive utility U from a consumption good $C$ and from health-or-survival rate $S$. The utility function can be presented as:

$$U = U(C, S) \tag{1}$$

We assume that the survival rate is related to the temperature $T$ and the consumption of health-maintaining good, $C_H$. The consumption of $C_H$ includes, for example, air conditioning, heat coolers, building construction and other technical solutions that are used to improve adaptation to temperature changes. The consumption of $C_H$ does not directly generate utility but it is purchased to increase probability of survival. The survival function can be expressed as follows:

$$S = S(C_H, T) \tag{2}$$

where temperature $T$ is, hence, treated as an exogenous variable in this model.

The budget constraint is:

$$C + p_H C_H = I \tag{3}$$

where $I$ is exogenous income. The price of other consumption goods is normalized to one. This type of model has been fully solved by Deschenes and Greenstone (2011). For our purpose, it is important to note that the above model shows an increase in the effective price of survival, that is, the above model predicts that $\frac{dS}{dT} \leq 0$ and $\frac{dC_H}{dT} \geq 0$. The key point is that the welfare effect of the exogenous change in temperature is reflected in the survival rate and in the consumption of the health-maintaining good $C_H$.

To explore the association between temperature and mortality, we apply the above model and present the following functional form:

$$M_t = f(T, C_H, Z) \tag{4}$$

which relates temperature ($T$) and the consumption of health-maintaining goods ($C_H$) (i.e. adaptation effect) and the impact on mortality ($M$) of other explanatory variables that contribute to health ($Z$). We predict that $\frac{dM}{dT} \geq 0$ and $\frac{dM}{dC_H} \leq 0$. Hence, the total effect of the temperature change on mortality is ambiguous.

## 3. Methods and materials

### 3.1 The empirical approach

Using standard panel methods found in health economics literature (Ruhm, 2000) and the climate economy literature (Dell *et al.*, 2014), the base of our estimated panel regression model takes the following common form:

$$m_{j,t} = \alpha + \beta temp_{j,t} + \gamma A_{j,t} + \delta Z_{j,t} + \mu_j + \theta_t + \varepsilon_{j,t}$$

where $Z$ is a vector of covariates, which are fully presented in the next section. A country ($j$) fixed effect ($\mu$) absorbs fixed spatial characteristics, such as the differences in life-styles across countries, and the time fixed effect ($\theta$) neutralizes any common trends and ensures that the relationship between temperature and mortality is identified from idiosyncratic country shocks.

Using the panel fixed-effects models to estimate the possible relationship between temperature and mortality, we are able to control for unobserved country- and time-specific effects that, if omitted, might produce biased coefficients. In this way, we can also take into account various country-specific factors that may affect mortality rates (e.g. latitude, geographical location, humidity, use of air conditioning and urban engineering). In particular, the individual country-specific determinants of adaptation may vary across countries, and the time-varying effects can be relatively easily accounted for when using panel-data techniques.

To identify adaptation to climate change, our strategy is to use the following generalized adaptation function:

$$A(\lambda, temp, D) = \left[\lambda_0 temp_t - \sum_{d=1}^{D} \lambda_d temp_{t-d}\right] \tag{5}$$

where $\lambda$ is a vector of adaptation parameters and $D$ is the number of periods during which the adaptation takes place. The parameter $\lambda_0$ gives the immediate short-run effect. A full long-run adaptation in temperature–mortality relation is evident, when $\lambda_d + \lambda_{d+1} + \ldots + \lambda_D = 0$.

### *3.2 Data description*

We use annual information on death rates from 23 Organisation for Economic Co-operation and Development (OECD) countries for the period from 1970 to 2010. The data availability on some cause-specific mortality rates constrained the start year. The overall mortality rate, the cause-specific mortality rates and the annual temperature data are obtained from the OECD Health Database. We selected as broad range of countries as possible to cover the different type's climatic environments among the 23 developed countries. The countries included are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, The Netherlands, New Zealand, Norway, Luxembourg, Portugal, Spain, Sweden, Switzerland, the UK and the USA. We examined the total cause-specific mortality rates (deaths/100,000 person) from 16 leading causes of death: disorders of blood, circulatory system disorder, digestive system disorder, endocrine disease, external events (e.g. accidents), genitourinary disorders, illness (e.g. viruses), infections, congenital malformations, malignant neoplasms, disorders of the nervous system, perinatal disorder, respiratory disorder, skin disease, suicide and tuberculosis. These specific diseases, disorders and events account for the majority of all deaths.

Table I shows the descriptive statistics of the annual average temperature and mortality rates of 23 OECD countries. The countries are divided into three temperature zones: hot zone (average annual temperature above 13°C), medium-hot zone (average annual temperature below 13°C but above 5°C) and cold zone (average annual temperature below 5°C). Countries in the hot temperature zone are Australia, Greece, Italy, Japan, New Zealand, Portugal and Spain; countries in the medium-hot temperature zone are Austria, Belgium, Denmark, France, Germany, Ireland, Luxembourg, The Netherlands, Switzerland, the UK and the USA; and countries in the cold temperature zone are Canada, Finland, Iceland, Norway and Sweden.

Australia had the highest annual mean temperature during 1960-2010 at 18.7°C, while Canada had the lowest, at 0.7°C. The highest total mortality rate (deaths/100,000 person) is recorded for Portugal, at 1,432.6, and the lowest for Germany, at 970.6.

We also gathered data for several covariate variables that have been identified in the literature as having a role in determining temperature mortality relation. The unemployment rate (*une*), measured as the share of unemployed workers of total labor force, is probably the most significant macroeconomic proxy variable that affects health production (Ruhm, 2000). The urbanization variable (*urb*), measured as the share

| | Temperature | | | Mortality | | |
|---|---|---|---|---|---|---|
| Country | Mean | Max | Min | Mean | Max | Min |
| *Hot temperature zone countries; annual average temperature is >13°C* | | | | | | |
| Australia | 18.7 | 19.9 | 17.6 | 1,148.3 | 1,623.8 | 673.3 |
| Greece | 17.7 | 19 | 16.7 | 1,127.3 | 1,416.7 | 819.7 |
| Italy | 15.3 | 16.8 | 13.6 | 1,174.5 | 1,586.2 | 699.2 |
| Japan | 14.6 | 16.1 | 13.4 | 1,061.4 | 1,792.2 | 613.4 |
| New Zealand | 13.1 | 14.9 | 12.2 | 1,225.7 | 1,581.5 | 764.7 |
| Portugal | 15.7 | 17 | 14.6 | 1,432.6 | 1,949.2 | 778.4 |
| Spain | 15 | 16.3 | 14 | 1,120 | 1,630.1 | 687.1 |
| *Medium-hot temperature zone countries; annual average temperature is 5-13°C* | | | | | | |
| Austria | 7.2 | 9.4 | 6 | 1,263.8 | 1,696.4 | 761.4 |
| Belgium | 10.2 | 11.6 | 7.9 | 1,286.8 | 1,697.2 | 822.5 |
| Denmark | 8.3 | 9.9 | 6.6 | 1,205.8 | 1,497.8 | 843.8 |
| France | 11.7 | 13.6 | 9.5 | 1,109.5 | 1,602 | 712.5 |
| Germany | 8.4 | 9.6 | 6.9 | 970.6 | 1,192.5 | 786.8 |
| Ireland | 9.8 | 10.9 | 8.7 | 1,379.4 | 1,772.9 | 775.4 |
| Luxembourg | 8.9 | 11 | 6.8 | 1,229.7 | 1,731.8 | 746.8 |
| The Netherlands | 9.8 | 11.2 | 7.8 | 1,115.3 | 1,395.8 | 768.8 |
| Switzerland | 6.4 | 9.2 | 2.8 | 1,085.7 | 1,591.9 | 678.9 |
| UK | 9.2 | 10 | 8.2 | 1,246.1 | 1,656 | 790.6 |
| USA | 11.7 | 12.8 | 11 | 1,170.7 | 1,551.7 | 822.8 |
| *Cold temperature zone countries; annual average temperature is <5°C* | | | | | | |
| Canada | 0.7 | 3.4 | −2.5 | 1,089.1 | 1,518.9 | 717.6 |
| Finland | 2.9 | 4.8 | 0.7 | 1,312 | 1,942.4 | 789.1 |
| Iceland | 4.3 | 5.8 | 2.4 | 1,028.7 | 1,310.4 | 749.3 |
| Norway | 2.5 | 4.8 | 0.1 | 1,100 | 1,434.5 | 762.3 |
| Sweden | 4.2 | 5.9 | 1.8 | 1,085.7 | 1,446.6 | 757 |

**Table I.** Descriptive statistics of the annual temperature and mortality rates in 23 OECD countries, 1960-2010

of the population living in cities, is included into the regression as urban areas are vulnerable to high concentrations of people and the influence of the urban heat effect (Kinney *et al.*, 2008). The age variable (*old*), which denotes the per cent of population over 65 years of age, is included as it is expected that mortality increases significantly as age increases. Further, the older people are the most susceptible to the extreme heat, and their adaptation abilities probably decrease significantly with higher age. The alcohol consumption variable (*alc*) (measured in liters per capita) is included as there is strong evidence that it increases the risk of several cause-specific mortalities (White *et al.*, 2002). Table A1 presents the descriptive statistics of the average annual control variables in 23 OECD countries.

## 4. Results and discussion

### *4.1 Short-run analysis*

We begin our empirical analysis by testing whether past temperature changes affected short-run mortality rate changes (i.e. we have not included the adaptation variable in the regressions). The use of lagged temperature changes is a crucial first step, as there is typically a lag between environmental changes and the production of health effects, as presented, for example, by Menz (2011) and Schwartz (2011). To explore short-run effects, we use the following regression:

$$\Delta m_{ij,t} = \beta_0 + \beta_1 \Delta temp_{ij,t-1} + \beta_2 \Delta Z_{ij,t} + \mu_{ij} + \theta_t + \upsilon_{ij,t} \tag{6}$$

where the sub-index $i$ refers to the cause of mortality, $j$ denotes the country, $t$ refers to time and $\upsilon_{ij,t}$ is the residual term.

Table II presents the results of a variety of specifications on the relationship between temperature and total mortality rates across 23 developed countries during the period from 1970 to 2010. We selected 1970 as our starting point for the short-run analysis, because the most of temperature increases occurred after that year (Barreca *et al.*, 2016). The main outcome, in the full sample analysis, is that the average temperature has a significant and a positive effect on the total mortality rate. This result is robust with respect to the different specifications. Also, the estimate is insensitive to the inclusion of country-specific trends and quadratic trend specifications. The fixed-effects estimate, in Column 6, gives the best fit for the temperature–mortality relationship. This leads us to conclude that the fixed-effects model with the additional covariates is the best base specification for the rest of our analysis.

For the full sample analysis, the results show that a 1 per cent increase in the annual average temperature leads to a modest increase in the total mortality rates (0.012 per cent). To put this effect in perspective, a 1 per cent increase in alcohol consumption leads to mortality rate increase that is 5-6 times higher than a similar increase in the temperature. The effect of unemployment on total mortality is negative. This is in line with the findings of Ruhm (2000), who uses US data that show a drop in death rates when unemployment increases. Neumeyer (2004) presents similar findings for Germany, and Gerdtham and Ruhm (2006) show similar findings for a panel of OECD countries for the period from 1960 to 1997. Ruhm (2000) notes that the decrease in mortality due to unemployment is related to a decrease in hazardous working conditions and less job-related stress. Also, during unemployment, it is easier for an individual to find the time to attend medical appointments and to take regular exercise. In the full sample analysis, the variables' urbanization and age seem to have no significant effects on the relationship between temperature and total mortality rates. The insignificance of the age variable probably reflects the fact that longevity markedly increased over the sample period.

Evidence shows that adaptation to temperature changes influences mortality rates. One way to explore whether the impact of temperature changes on mortality rates has changed because of adaptation is to compare the effects across sub-periods. Here, we divide our data into two sample periods. The first period covers the years 1970-1989, and the second period covers the period from 1990 to 2010. This choice is rather arbitrary; but here, we follow Barreca *et al.* (2016), who states that in the USA, the adaptation effect due to air conditioning and engineering has increased markedly since the 1980s. Also, splitting the sample into two same-sized sub-periods makes it possible to compare the estimation results of different sub-periods; also, this likely decreases the regression specification errors that can occur when different sample sizes are used.

Columns 7 and 8 in Table II show separate estimates for the 1970-1989 and 1990-2010 periods. As we can see, the relationship between temperature and mortality is significant and positive at the 5 per cent level of significance for the period of 1970-1989, but it is not significant for the period of 1990-2010. This provides the first evidence of the adaptation effect in the temperature–mortality relationship.

Table III presents the basic fixed-effects-model estimation results for the cause-specific mortality rates. The regression specification is similar to that of the fixed-effects

**Table II.** Estimation results of the lagged temperature change effects on mortality changes

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| Δtemp | 0.014*** (0.004) | 0.014*** (0.005) | 0.14*** (0.005) | 0.014*** (0.004) | 0.012*** (0.004) | 0.012*** (0.004) | 0.014*** (0.005) | 0.005 (0.009) |
| Δalc | | 0.065*** (0.002) | 0.062*** (0.002) | 0.062*** (0.002) | | 0.066*** (0.002) | 0.093*** (0.031) | 0.013 (0.035) |
| Δurb | | −0.078 (0.235) | −0.107 (0.297) | −0.111 (0.295) | | 0.039 (0.278) | −0.349 (0.438) | 0.923* (0.538) |
| Δune | | −0.016*** (0.007) | −0.016** (0.007) | −0.016** (0.007) | | −0.025*** (0.007) | −0.032*** (0.011) | −0.026** (0.011) |
| Δold | | −0.096 (0.113) | −0.101 (1.49) | −0.107 (0.148) | | −0.003 (0.151) | −0.373 (0.278) | 0.223 (0.217) |
| Countries | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 |
| Period | 1970-2010 | 1970-2010 | 1970-2010 | 1970-2010 | 1970-2010 | 1970-2010 | 1970-1989 | 1990-2010 |
| Obs. | 895 | 868 | 868 | 868 | 895 | 868 | 436 | 432 |
| $R^2$ | 0.011 | 0.030 | 0.049 | 0.041 | 0.229 | 0.251 | 0.257 | 0.293 |
| Individual trends | No | No | Yes | Yes | No | No | No | No |
| Quadratic trend | No | No | No | Yes | No | No | No | No |

**Notes:** ***, **and *denote significance at the 1, 5 and 10 % levels, respectively. Equation (6) is estimated with different specifications so that each column corresponds to a separate regression. Specifications (1)-(4) = pooled; Specifications (5) and (6) = fixed; Specification (7) = fixed, 1970-1989; Specification (8) = fixed, 1990-2010. All variables are transformed into natural logarithms. The dependent variable is Δ*mor*, which refers to once differenced total mortality rate; Δalc: once differenced alcohol consumption; Δurb: once differenced urbanization rate; Δune: once differenced unemployment rate; and Δold: once differenced age variables model with additional covariates (Table II; Column 6). To save space, we do not report the estimation results for the cause-specific mortalities that are not significant in any period. In the full sample analysis, 4 out of 16 cause-specific mortality rates have a positive and significant relationship temperature changes. In the sub-sample analysis, we find four significant relationships in the first period and only two in the second period. We further estimate the sub-sample from 2000 to 2010. Here, we find no positive and significant relationship between temperature and cause-specific mortality at the 5 per cent level of significance. This reflects the evidence of the adaptation effect and confirms the findings presented in Table II.

An interesting question is whether the temperature–mortality relationship, in a particular temperature area, is dependent on the temperature level. Table IV presents the estimation results for the different temperature zones. Clearly, we note the differences in the temperature–mortality relationship between temperature zones during the period from 1970 to 2010. The relationship between changes in the overall mortality and changes is significant at the 1 per cent level of significance in both the cold and hot temperature zones, but only at the 10 per cent level of significance in the medium-hot temperature zone. However, the magnitude of the effect is much higher in the hot temperature zone (0.318) than in the cold (0.012) or medium-hot temperature (0.031) zones. Hence, in developed countries where the average annual temperature is over 13°C, the effect of a 1 per cent increase in temperature leads to a 0.318 per cent increase in the overall mortality rates, on average. In general, there seem to be more significant relationships between temperature and mortality in countries in the hot temperature zone, and the impacts seem to be at much higher levels relative to those in countries in other temperature zones.

We also find, in the data, that the adaptation effect differs among the different temperature-zones. For the cold temperature zone, at the 5 per cent level of significance, we find two significant cause-specific mortality rates (circulatory disorder and infectious diseases) during the period from 1970 to 1989, and none from 1990 to 2010. For countries in the medium-hot temperature zone, at the 5 per cent level of significance, we find four significant mortality relationships (circulatory disorder, digestive disorder, perinatal disorder and skin diseases) during the first sample period, but none during the second sample period. For countries in the hot temperature zone, the results show five significant relations at the 5 per cent level of significance (diseases of the

**Table III.**
The effect of the lagged temperature change on the cause-specific mortality rates

| | Full sample | 1970-1989 | 1990-2010 | 2000-2010 |
|---|---|---|---|---|
| Circulatory disorder | 0.016*** (0.051) | 0.018*** (0.006) | 0.009 (0.012) | −0.056 (0.015) |
| Digestive disorder | 0.028** (0.011) | 0.021* (0.011) | 0.062** (0.026) | 0.028 (0.036) |
| Illness | 0.016 (0.032) | 0.045 (0.037) | −0.109 (0.073) | −0.189*** (0.078) |
| Infections | 0.041 (0.026) | 0.059** (0.031) | −0.041 (0.059) | −0.156*** (0.076) |
| Nervous disorder | −0.019 (0.018) | −0.013 (0.022) | −0.063 (0.049) | −0.123** (0.058) |
| Respiratory disorder | 0.037** (0.017) | 0.028 (0.021) | 0.071** (0.034) | 0.045 (0.043) |
| Suicide | 0.004 (0.017) | −0.001 (0.020) | 0.035 (0.034) | 0.102* (0.062) |
| Tuberculosis | 0.094* (0.062) | 0.122*** (0.053) | −0.031 (0.134) | −0.002 (0.075) |

**Notes:** ***, **and *denote significance at the 1, 5 and 10 % levels, respectively. The equations are estimated with country-fixed effects and year-fixed effects. Equation (6) is estimated for each mortality cause. The rows, where all of the estimates are not statistically significant, are omitted from the table

**Table IV.** Lagged temperature change effect on mortalities (changes)

| | Cold | | | Medium | | | Hot | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1970-2010 | 1970-1989 | 1990-2010 | 1970-2010 | 1970-1989 | 1990-2009 | 1970-2010 | 1970-1989 | 1990-2010 | 2000-2010 |
| Blood disorder | 0.045 (0.076) | 0.066 (0.097) | −0.004 (0.169) | −0.009 (0.146) | 0.059 (0.203) | −0.161 (0.224) | 1.064*** (0.371) | 1.418*** (0.513) | 0.867 (0.561) | 0.261 (0.944) |
| Circulatory disorder | 0.017*** (0.006) | 0.019*** (0.007) | 0.019 (0.017) | 0.051*** (0.020) | −0.016*** (0.003) | −0.040 (0.031) | 0.381*** (0.069) | 0.309*** (0.120) | 0.437*** (0.077) | 0.259 (0.153) |
| Digestive disorder | 0.024 (0.022) | 0.020 (0.025) | 0.055 (0.059) | 0.061* (0.036) | −0.089 (0.131) | −0.024 (0.062) | 0.437*** (0.109) | 0.285* (0.168) | 0.487*** (0.147) | 0.461 (0.307) |
| Endocrine disorder | 0.014 (0.043) | 0.059 (0.051) | −0.159 (0.102) | −0.060 (0.082) | −0.084 (0.111) | −0.002 (0.129) | 0.271 (0.235) | 0.316 (0.433) | 0.283 (0.219) | 0.576* (0.316) |
| External accidents | 0.018 (0.019) | 0.017 (0.018) | −0.04 (0.056) | 0.001 (0.035) | 0.025 (0.045) | −0.047 (0.065) | 0.428*** (0.106) | 0.414** (0.174) | 0.431*** (0.123) | 0.304 (0.226) |
| Genitourinary disorder | −0.021 (0.029) | −0.022 (0.029) | −0.11 (0.092) | 0.061 (0.070) | 0.123 (0.085) | −0.055 (0.122) | 0.410*** (0.172) | 0.188 (0.251) | 0.578** (0.243) | 0.172 (0.387) |
| Illness | −008 (0.005) | 0.016 (0.069) | −0.113 (0.078) | 0.006 (0.108) | 0.165 (0.137) | −0.319* (0.182) | 0.034 (0.379) | 0.480 (0.365) | −0.352 (0.689) | 0.357 (0.715) |
| Infections | 0.082* (0.043) | 0.112** (0.053) | −0.069 (0.995) | 0.075 (0.107) | 0.202 (0.126) | −0.195 (0.187) | 0.449** (0.234) | 0.686 (0.372) | 0.272 (0.289) | 0.054 (0.551) |
| Malformations | 0.024 (0.044) | 0.001 (0.037) | 0.068 (0.152) | −0.032 (0.129) | −0.076 (0.119) | 0.021 (0.263) | −2.89 (0.236) | −0.852** (0.382) | 0.173 (0.291) | −0.053 (0.566) |
| Mortality | 0.012*** (0.004) | 0.013** (0.005) | 0.001 (0.001) | 0.031* (0.017) | 0.073*** (0.022) | −0.044* (0.025) | 0.318*** (0.064) | 0.272** (0.115) | 0.341*** (0.069) | 0.210 (0.142) |
| Neoplasm disorder | 0.001 (0.006) | 0.002 (0.008) | 0.001 (0.015) | −0.014 (0.016) | −0.03 (0.022) | 0.021 (0.028) | 0.038 (0.037) | 0.013 (0.063) | 0.044 (0.041) | 0.009 (0.007) |
| Nervous disorder | −0.004 (0.027) | −0.004 (0.004) | −0.008 (0.005) | 0.049 (0.082) | 0.175 (0.102) | −0.162 (0.140) | 0.152 (0.189) | 0.391* (0.231) | −0.064 (0.296) | 0.386 (0.547) |
| Perinatal | −0.045 (0.059) | −0.003 (0.004) | −1.33 (0.222) | 0.187 (0.127) | 0.309** (0.141) | −0.073 (0.234) | 0.589** (0.258) | 0.232 (0.449) | 0.798*** (0.301) | 0.717 (0.553) |
| Respiratory disorder | 0.028 (0.022) | 0.017 (0.028) | 0.085* (0.005) | 0.059 (0.065) | 0.155* (0.095) | −0.137 (0.087) | 0.739*** (0.220) | 0.422 (0.362) | 0.969*** (0.275) | 0.632 (0.489) |
| Skin disorder | 0.055 (0.065) | 0.073 (0.077) | −0.009 (0.145) | −0.582*** (0.186) | −539** (0.225) | −0.654** (0.323) | 0.991* (0.598) | −0.241 (0.893) | 1.774** (0.801) | 1.645 (1.56) |
| Suicide | 0.017 (0.027) | 0.013 (0.003) | 0.037 (0.006) | 0.020 (0.064) | 0.034 (0.077) | −0.030 (0.113) | 0.115 (0.189) | −0.098 (0.252) | 0.218 (0.291) | 0.699 (0.636) |
| Tuberculosis | 0.123 (0.008) | 0.140 (0.009) | 0.086 (0.251) | 0.082 (0.206) | 0.339 (0.248) | −0.430 (0.365) | −0.388 (0.492) | 0.831 (0.581) | −1.341* (0.803) | 1.428 (0.1.48) |

**Notes:** ***, ** and *denote significance at the 1, 5 and 10 % levels, respectively. The mortality causes with no significant relations are omitted from the table. Equation (6) is estimated for total mortality and each mortality cause blood, circulatory system disorder, external events and congenital malfunctions) during the period from 1970 to1989 and eight significant relationship (circulatory system disorder, digestive system disorder, external events, genitourinary disorder, nervous system disorder, perinatal disorder, respiratory disorder, skin diseases and tuberculosis) during the period from 1990 to 2010. However, when we use the sub-period of 2000-2010, there are no significant relationships at the 5 per cent level of significance. Hence, we may conclude that the adaptation effect is also present in countries in the hot temperature zone.

### *4.2 Long-run adaptation and the threshold effect analyses*

*4.2.1 Adaptation effects.* Next, we present a more in-depth estimate of the adaptation effects. Menz (2011) investigated the concept of human adaptation to environmental changes. In his study, he included current and lagged air pollution variables in life-satisfaction regressions to explore whether people habituate to increasing levels of air pollution. We follow his approach and explore the adaptation effect in the relationship between temperature and mortality by estimating the following level-form panel fixed-effects model:

$$m_{ij,t} = \beta_0 + \sum_{k=0}^{n} \varphi_{ij,t-k} temp_{ij,t-k} + \sum_{l=1}^{m} \phi_{ij,t-l} m_{i,t-l} + \beta_1 Z_{ij,t} + \mu_{ij} + \theta_t + \upsilon_{ij,t} \qquad (7)$$

where $k$ and $l$ denote lag lengths for the short-run dynamics. In the above dynamic fixed-effects model, $\phi_{ij}$ represents the effect of the current temperature on mortality, and the sum of the coefficients, i.e. $\phi_{ij,t} + \phi_{ij,t-1} \ldots + \phi_{ij,t-n}$, gives the full temperature effect on mortality $i$ in country $j$. Now, if we are able to accept the null hypothesis that $H_0$: $\phi_{ij,t} + \phi_{ij,t-1} \ldots + \phi_{ij,t-n}$, then we can say that there is total adaptation to temperature changes.

Our estimation results are summarized in Table V. The number of lags is set as $n = m = 2$. The adaptation effect on the total mortality rate (*mor*) can be rejected at the 10 per cent level of significance. The results on Table V shows that there seems to be a full adaptation effect, as evidenced in most of the cause-specific mortality rates. There is only one cause-specific mortality rate, namely, congenital malformation, for which full adaptation can be rejected at the 5 per cent level of significance. At the 10 per cent level of significance, the adaptation effect can also be rejected for two other cause-specific mortality rates, namely, diseases of the nervous system and infectious diseases.

If the adaptation effect is rejected, then we can proceed to compute the long-run effects of a change in temperature on mortality rates as follows:

$$LR - effect = \frac{\sum_{k=0}^{n} \phi_{ij,t-k}}{1 - \sum_{l=1}^{m} \varphi_{ij,t-l}} \qquad (8)$$

The long-run effect of total mortality is now 0.16, meaning that a 1 per cent increase in the temperature leads to a 0.16 per cent increase in the total mortality rate in the long run. For the long-run effects of cause-specific mortality, the rates of increase of infectious disease,

**Table V.** Mortality adaptation to temperature level changes (all countries)

| Mortality cause | blo | cir | dia | dig | end | ext | gen | ill | inf | mal |
|---|---|---|---|---|---|---|---|---|---|---|
| Temp (standard error) | 0.03 (0.04) | −0.01 (0.14) | 0.01 (0.03) | −0.02 (0.01) | 0.01 (0.03) | −0.01 (0.01) | −0.01 (0.02) | −0.03 (0.04) | −0.04 (0.03) | −0.02 (0.03) |
| Temp (−1) | 0.03 (0.05) | 0.01 (0.00) | −0.01 (0.03) | 0.02 (0.01) | 0.01 (0.02) | 0.00 (0.01) | −0.00 (0.02) | 0.04 (0.04) | 0.05 (0.03) | 0.04 (0.03) |
| Temp (−2) | 0.02 (0.04) | −0.01 (0.01) | 0.01 (0.03) | −0.01 (0.01) | 0.04 (0.03) | 0.00 (01) | 0.04 (0.02) | 0.02 (0.04) | 0.01 (0.03) | 0.03 (0.03) |
| Σtemp | 0.087 | −0.006 | 0.029 | −0.008 | 0.054 | −0.003 | 0.020 | 0.031 | 0.026 | 0.062 |
| Prob ($\Sigma$temp $> F$) ($p$-value) | 2.36 (0.13) | 0.53 (0.47) | 0.48 (0.49) | 0.22 (0.63) | 2.19 (0.14) | 0.05 (0.86) | 0.57 (0.45) | 1.73 (0.19) | 0.46 (0.50) | 2.34 (0.13) |
| Σtemp (lags) | 0.054 | 0.009 | 0.014 | 0.009 | 0.047 | 0.003 | 0.032 | 0.062 | 0.067 | 0.078 |
| Prob ($\Sigma$templags $> F$) ($p$-value) | 0.97 (0.32) | 1.28 (0.25) | 0.13 (0.72) | 0.28 (0.59) | 1.77 (0.18) | 0.04 (0.83) | 1.62 (0.20) | 1.73 (0.19) | 3.16 (0.08) | 3.95 (0.04) |
| Long-run effect | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.45 | 0.22 |
| $N$ | 852 | 861 | 861 | 861 | 861 | 861 | 861 | 861 | 861 | 861 |
| $R^2$ | 0.77 | 0.99 | 0.88 | 0.96 | 0.90 | 0.96 | 0.92 | 0.97 | 0.89 | 0.85 |

**Notes:** The dependent variables are natural logs of each mortality cause. Equation (7) is estimated with country-fixed effects and year-fixed effects. Standard errors are displayed in parenthesis below estimated coefficients. Definitions of variables: temp: temperature rate; blo: blood; cir: circulatory; dia: diabetes; dig: digestive; end: endocrine; ext: external; gen: genitourinary; ill: illness; inf: infectious; mal: malformations; men: mental; mor: mortality; neo: neoplasm; ner: nervous; per: perinatal; res: respiratory; ski: skin; sui: suicide; tub: tuberculosis. Each column corresponds to a separate regression. The long-run effects display the estimation results of equation (8). All equations include control factors (age, alcohol, urbanization and unemployment) and lagged mortality cause. All variables are transformed into natural logarithms

(*continued*)

Table V.

| Mortality cause | men | mor | neo | ner | per | res | ski | sui | tub |
|---|---|---|---|---|---|---|---|---|---|
| Temp (standard error) | −0.03 (0.06) | −0.01 (0.01) | −0.00 (0.00) | 0.02 (0.02) | 0.02 (0.04) | −0.01 (0.02) | 0.02 (0.06) | −0.00 (0.02) | −0.01 (0.06) |
| Temp (−1) | 0.07 (0.05) | 0.01 (0.00) | 0.00 (0.00) | 0.01 (0.02) | 0.01 (0.04) | 0.03 (0.02) | −0.07 (0.06) | −0.01 (0.02) | 0.07 (0.06) |
| Temp (−2) | −0.02 (0.05) | −0.00 (0.01) | 0.00 (0.00) | 0.02 (0.02) | 0.02 (0.03) | −0.01 (0.02) | −0.03 (0.05) | −0.01 (0.02) | −0.06 (0.06) |
| Σtemp | 0.007 | 0.002 | 0.001 | 0.057 | 0.056 | −0.003 | −0.077 | −0.029 | −0.008 |
| Prob (Σtemp > $F$) ($p$-value) | 0.00 (0.92) | 0.73 (0.79) | 0.05 (0.82) | 3.70 (0.05) | 1.49 (0.22) | 0.02 (0.89) | 1.19 (0.27) | 1.27 (0.26) | 0.01 (0.91) |
| Σtemp (lags) | 0.040 | 0.011 | 0.002 | 0.035 | 0.033 | 0.008 | −0.102 | −0.025 | 0.006 |
| Prob (Σtemplags > $F$) ($p$-value) | 0.37 (0.54) | 3.36 (0.07) | 0.16 (0.68) | 1.54 (0.21) | 0.54 (0.46) | 0.11 (0.73) | 2.19 (0.14) | 1.05 (0.30) | 0.001 (0.92) |
| Long-run effect | 0 | 0.16 | 0 | 0.50 | 0 | 0 | 0 | 0 | 0 |
| $N$ | 854 | 861 | 861 | 861 | 861 | 861 | 803 | 883 | 840 |
| $R^2$ | 0.93 | 0.98 | 0.97 | 0.93 | 0.92 | 0.93 | 0.86 | 0.97 | 0.94 |

congenital malformations and diseases of the nervous system are 0.45, 0.22 and 0.50, respectively.

*4.2.2 Non-linear effects on the annual temperature changes.* Finally, we explored whether there exists asymmetry in the relationship between temperature and the cause-specific mortality rates. More specifically, we estimate whether there exist specific threshold increases/decreases in the annual temperature rates that lead to changes in mortality rates. We explore whether large temperature changes affect cause-specific mortalities similar to effects of small temperature changes. Our analysis is based on the following regression equation:

$$m_{ij,t} = \beta_0 + \sum_{k=0}^{n} \phi_{ij,t-k} temp_{ij,t-k} {}^{*} D_{ij} + \sum_{l=1}^{m} \varphi_{ij,t-l} m_{i,t-l} + \beta_1 Z_{ij,t} + \mu_{ij} + \theta_t + v_{ij,t} \tag{9}$$

where $D_{ij} = 1$ if the per cent $\Delta temp_t >$ per cent *threshold level*; otherwise, it is equal to 0. Our interest is in the null hypothesis $H_0$: $\phi_{ij,t} + \phi_{ij,t-1} \ldots + \phi_{ij,t-n}$.

Figure 1 presents threshold temperature change effects on various mortalities. We find that for overall mortality and the seven cause-specific mortality rates, diseases of the circulatory system, external events, congenital malformations, malignant neoplasms, perinatal disease, respiratory disease and suicides, there are annual temperature change threshold levels that lead to a significant increase in mortality. We find, perhaps unsurprisingly, that cause-specific mortality rates seem to increase more with temperature increases than with temperature decreases. Our results indicate that the overall mortality rate has threshold temperature change effect. In developed countries, for a 5 per cent increase in the annual average temperature, there is a significant ($F$-test = 3.62, $p$-value = 0.027) increase in the overall mortality rate.

In Figure 1, we also include the threshold effects in terms of absolute variations in temperature when the average annual temperature is 10°C. For example, in countries like Belgium, France, Ireland and the UK, our results indicate that after a 0.5°C increase in the annual average temperature, there will be a significant increase in temperature-related mortality. In contrast, for decreasing temperatures, we are unable to find any threshold effects. For circulatory disease-, congenital malformation-, neoplasm malignancy-, perinatal disease- and suicide-specific mortalities, temperature rate increases cause changes in mortalities, but when the temperature decreases, the changes in mortality rates do not occur. For external events- and respiratory disease-specific mortalities, there exist significant changes after a decrease in the annual temperature rates, but not when the temperature increases.

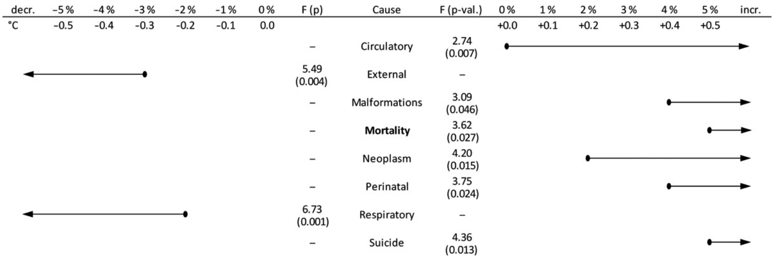

**Figure 1.**
Threshold temperature effect on the mortality rates

## 5. Conclusions

In the twenty-first century, climate change will affect well-being in multiple ways. The Intergovernmental Panel on Climate Change's (2014) latest evaluation predicts that global temperatures will increase by between 1.5°C and 4.6°C by 2100. Despite the current extensive research, finding an accurate estimation of the temperature effects on mortality is a rather complex task. First, forecasts significantly vary for increases in the global average temperature, indicating uncertainty about the sensitivity of the climatic system. Second, when analyzing the relationship between temperature and mortality, human adaptation, climate engineering and mitigation effects play an important role.

This study contributes to the previous literature in many important ways. First, we perform our investigation in the context of several countries. This allows us to make more convincing conclusions about the adaptation effect on the temperature–mortality relationship. Second, we use both short- and long-run analyzes to emphasize the relationship between temperature change and cause-specific mortality rates. Third, we take into account the human adaptation effect. More specifically, we provide a clear evidence of the adaptation effect in temperature–mortality relationships in 23 developed countries for a 30-year period from 1970 to 2010. Our analysis shows that humans have been quite adaptive to the small annual changes in temperature levels. Also, annual changes in temperature levels have clear impacts on only some cause-specific mortalities. The results are robust in the sense that the relationship between temperature and mortality does not change even if we also take into account the socio-economic factors, such as welfare costs and the unemployment rate.

Our analysis predicts that for developed countries, if we are able to keep the annual temperature changes to less than 5 per cent, or to approximately between −0.5°C and +0.5°C, then temperature-related mortalities will not increase. Our findings indicate that if no other effects occur, then this target temperature change will allow people and society to adapt to climate change. However, we should point out the tipping points, that are also important factors here, such as the rapid melting of ice sheets, changes in ocean circulation and feedback processes in warming, where warming leads to more warming. Once they begin, these tipping points are not easily reversed; however, our analysis is unable to take these important factors into account.

As a policy recommendation, we suggest that when analyzing climate change effects on health production, it is important to take into account the adaptation effects. Further, it is crucial to recognize that the adaptation effect might differ in different temperature zones. Policy changes in the hotter temperature regions, in particular, should be more rapid, as the temperature change effects on mortality are higher in not regions than in cold regions.

For the future research, we suggest that better understanding of climatic change effects on public health would take into account the effects of temperature variations and temperature thresholds on cause-specific mortality rates. Furthermore, as air pollution usually increases concurrently with temperature increases, this synchronous behavior should be taken into account when predicting the climate change effects on human health production. Further, because humans are able to adapt to changing climatic conditions, it is crucial to include more specific climatic engineering and/or adaptation variables in the analysis.

## References

Ackerman, F. and Stanton, E.A. (2008), "A comment on economy-wide estimates of the implications of climate change: Human health", *Ecological Economics*, Vol. 66 No. 1, pp. 8-13.

Barreca, A.I. (2012), "Climate change, humidity, and mortality in the United States", *Journal of Environmental Economics and Management*, Vol. 63 No. 1, pp. 19-34.

Barreca, A., Clay, K., Deschenes, O., Greenstone, M. and Shapiro, J.S. (2016), "Adapting to climate change: the remarkable decline in the US temperature-mortality relationship over the twentieth century", *Journal of Political Economy*, Vol. 124 No. 1, pp. 105-159.

Bosello, F., Roson, R. and Tol, R.S.J. (2006), "Economy-wide estimates of the implications of climate change: human health", *Ecological Economics*, Vol. 58 No. 3, pp. 579-591.

Dell, M., Jones, B.F. and Olken, B.A. (2014), "What do we learn from the weather? The new climate-economy literature", *Journal of Economic Literature*, Vol. 52 No. 3, pp. 740-798.

Deschenes, O. (2014), "Temperature, human health, and adaptation: a review of the empirical literature", *Energy Economics*, Vol. 46 No. 1, pp. 606-619.

Deschenes, O. and Moretti, E. (2009), "Extreme weather events, mortality, and migration", *Review of Economics and Statistics*, Vol. 91 No. 4, pp. 659-681.

Deschenes, O. and Greenstone, M. (2011), "Climate change, mortality, and adaptation: evidence from annual fluctuations in weather in the US", *American Economics Journal: Applied Economics*, Vol. 3 No. 4, pp. 152-185.

Gerdtham, U.G. and Ruhm, C.J. (2006), "Death rise in good economic times: evidence from the OECD", *Economics & Human Biology*, Vol. 4 No. 3, pp. 298-316.

Grossman, M. (2000), "The human capital model", in Culyer, A.J. and Newhouse, J.P. (Eds), *Handbook of Health Economics*, Elsevier Science, North-Holland, pp. 347-408.

Haines, A., Kovats, R.S., Campbell-Lendrum, D. and Corvalan, C. (2006), "Climate change and human health: impacts, vulnerability, and mitigation", *Lancet*, Vol. 367 No. 9528, pp. 2101-2109.

Hajat, S., Vardoulakis, S., Heaviside, C. and Eggen, B. (2014), "Climate change effects on human health: projections of temperature-related mortality for the UK during 2020s, 2050s and 2080s", *Journal of Epidemiology and Community Health*, Vol. 68 No. 7, pp. 641-648.

Hübler, M., Klepper, S. and Peterson, S. (2008), "Costs of climate change: the effects of rising temperature on health and productivity in Germany", *Ecological Economics*, Vol. 68 Nos 1/2, pp. 381-393.

Intergovernmental panel on climate change (IPCC) (2014), *Climate Change 2014: Impacts, Adaptation and Vulnerability*, Cambridge University Press, Cambridge and NY, NY, USA.

Kinney, P.L., O'Neill, M.S., Bell, M.L. and Schwartz, J. (2008), "Approach for estimating effects of climate change on heat-related deaths: Challenges and opportunities", *Environmental Science & Policy*, Vol. 11 No. 1, pp. 87-96.

McMichael, A.J., Woodruff, R.E. and Hales, S. (2006), "Climate change and human health: present and future risks", *Lancet*, Vol. 367 No. 9513, pp. 859-869.

Menz, T. (2011), "Do people habituate to air pollution? Evidence from international life satisfaction data", *Ecological Economics*, Vol. 71 No. 20, pp. 211-219.

Neumeyer, E. (2004), "Recessions lower (some) mortality rates: evidence from Germany", *Social Science and Medicine*, Vol. 58 No. 6, pp. 1037-1047.

Ruhm, C.J. (2000), "Are recessions good for your health?", *Quarterly Journal of Economics*, Vol. 115 No. 2, pp. 617-650.

Schwartz, J. (2011), "Long-term effects of particulate air-pollution on human health", in Nriagu, J.O. (Ed.), *Encyclopedia of Environmental Health*, Elsevier Inc., pp. 520-527.

Tol, R.S.J. (2002), "Estimates of the damage costs of climate change. Part 1: benchmark estimates", *Environmental and Resource Economics*, Vol. 21 No. 1, pp. 47-73.

Watkiss, P. and Hunt, A. (2012), "Projection of economic impacts of climate change in sectors of Europe based on bottom up analysis: human health", *Climatic Change*, Vol. 112 No. 1, pp. 101-126.

White, I.R., Altman, D.R. and Nanchahal, K. (2002), "Alcohol consumption and mortality: modelling risks for men and women at different ages", *British Medical Journal*, Vol. 325 No. 7357, pp. 191-198.

WHO (World Health Organization) (2014), *Quantitative Risk Assessment of the Effects of Climate Change on Selected Causes of Death, 2030s and 2050s*, World Health Organization, Geneva, available at: http://apps.who.int/iris/bitstream/10665/134014/1/9789241507691_eng.pdf (accessed 2 April 2016).

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## Appendix

**Table A1.** Descriptive statistics of the control variables in 23 OECD countries during 1960-2010

| | Alcohol | | | | Urbanization | | | | Unemployment | | | | Age | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Max | Min | AR(1) | Mean | Max | Min | AR(1) | Mean | Max | Min | AR(1) | Mean | Max | Min | AR(1) |
| Australia | 11.24 | 13.10 | 9.80 | 0.951*** | 85.79 | 89.05 | 81.53 | 0.967*** | 5.60 | 10.90 | 1.10 | 0.926*** | 10.53 | 13.45 | 8.35 | 1.015*** |
| Austria | 14.17 | 15.60 | 12.50 | 0.857*** | 65.66 | 67.45 | 64.72 | 1.070*** | 3.07 | 5.20 | 1.10 | 0.946*** | 14.82 | 17.60 | 12.22 | 1.000*** |
| Belgium | 11.80 | 13.50 | 9.70 | 0.903*** | 95.52 | 97.46 | 92.46 | 0.976*** | 6.70 | 10.80 | 1.50 | 0.950*** | 14.79 | 17.43 | 11.99 | 0.995*** |
| Canada | 8.99 | 10.90 | 7.20 | 0.967*** | 76.45 | 80.55 | 69.06 | 0.944*** | 7.55 | 12.00 | 3.40 | 0.902*** | 10.34 | 14.11 | 7.50 | 1.014*** |
| Denmark | 11.81 | 13.10 | 8.60 | 0.927*** | 82.75 | 86.80 | 73.69 | 0.943*** | 4.95 | 10.40 | 0.70 | 0.902*** | 14.06 | 16.45 | 10.60 | 0.972*** |
| Finland | 8.46 | 10.40 | 5.80 | 0.947*** | 73.28 | 83.56 | 55.29 | 0.972*** | 6.51 | 16.80 | 1.20 | 0.929*** | 12.26 | 17.23 | 7.20 | 0.999*** |
| France | 16.76 | 20.80 | 12.70 | 1.001*** | 73.89 | 85.23 | 61.88 | 0.991*** | 6.58 | 11.10 | 1.10 | 0.971*** | 14.11 | 16.79 | 11.65 | 1.001*** |
| Germany | 13.16 | 14.80 | 11.80 | 0.832*** | 72.77 | 73.82 | 71.38 | 0.969*** | 5.38 | 11.30 | 0.55 | 0.952*** | 15.30 | 20.38 | 11.52 | 1.023*** |
| Greece | 9.84 | 13.20 | 6.70 | 0.862*** | 56.09 | 61.22 | 42.89 | 0.937*** | 6.60 | 12.60 | 1.70 | 1.004*** | 13.62 | 18.55 | 8.25 | 0.994*** |
| Ireland | 10.81 | 14.40 | 7.00 | 0.958*** | 55.37 | 61.90 | 45.82 | 0.971*** | 8.97 | 16.80 | 3.90 | 0.947*** | 11.15 | 11.67 | 10.79 | 1.015*** |
| Island | 5.04 | 7.50 | 3.80 | 0.990*** | 88.66 | 93.62 | 80.30 | 0.969*** | 1.95 | 7.56 | 0.08 | 0.981*** | 10.14 | 12.02 | 7.95 | 0.991*** |
| Italy | 12.76 | 19.90 | 7.80 | 1.003*** | 65.71 | 68.22 | 59.36 | 0.930*** | 7.53 | 11.30 | 3.90 | 0.943*** | 14.44 | 20.35 | 9.51 | 1.009*** |
| Japan | 7.84 | 9.20 | 6.10 | 0.941*** | 76.53 | 90.54 | 63.27 | 1.003*** | 2.70 | 5.40 | 1.10 | 1.005*** | 11.83 | 22.69 | 5.73 | 1.033*** |
| Luxembourg | 14.85 | 17.90 | 12.70 | 0.820*** | 79.28 | 85.19 | 69.56 | 0.970*** | 1.88 | 5.20 | 0.00 | 0.980*** | 13.18 | 14.30 | 10.83 | 0.933*** |
| The Netherlands | 10.26 | 12.20 | 7.80 | 0.917*** | 68.73 | 82.75 | 59.75 | 1.024*** | 4.19 | 8.30 | 0.50 | 0.917*** | 11.94 | 15.31 | 8.93 | 1.008*** |
| New Zeeland | 10.19 | 12.10 | 8.70 | 0.941*** | 83.23 | 86.19 | 76.00 | 0.940*** | 3.79 | 10.70 | 0.00 | 0.957*** | 10.25 | 13.01 | 8.14 | 1.021*** |
| Norway | 5.36 | 6.60 | 4.60 | 0.954*** | 69.58 | 79.10 | 49.92 | 0.942*** | 2.85 | 6.60 | 0.70 | 0.933*** | 14.37 | 16.31 | 11.11 | 0.950*** |
| Portugal | 15.01 | 20.80 | 11.40 | 0.778*** | 46.35 | 60.51 | 34.96 | 1.013*** | 5.81 | 12.00 | 1.80 | 0.983*** | 12.71 | 17.94 | 7.98 | 1.005*** |
| Spain | 14.38 | 19.60 | 9.90 | 0.974*** | 71.41 | 77.28 | 56.57 | 0.947*** | 10.20 | 21.30 | 1.20 | 0.977*** | 12.72 | 16.97 | 8.18 | 0.996*** |
| Sweden | 6.59 | 7.70 | 5.80 | 0.887*** | 82.04 | 85.06 | 72.49 | 1.013*** | 4.18 | 9.90 | 1.20 | 0.966*** | 15.95 | 18.24 | 11.97 | 0.969*** |
| Switzerland | 12.56 | 15.00 | 10.10 | 1.012*** | 64.67 | 73.64 | 51.02 | 0.982*** | 1.51 | 4.20 | 0.00 | 0.990*** | 13.56 | 16.70 | 10.18 | 0.995*** |
| UK | 9.60 | 11.50 | 7.10 | 0.916*** | 78.28 | 79.51 | 77.12 | 1.037*** | 5.83 | 11.20 | 1.10 | 0.941*** | 14.66 | 16.59 | 11.72 | 0.975*** |
| USA | 9.26 | 10.40 | 8.10 | 0.957*** | 75.59 | 82.14 | 70.00 | 1.011*** | 6.00 | 9.70 | 3.50 | 0.824*** | 11.38 | 13.06 | 9.19 | 0.985*** |

**Note:** ***, ** and * denote significance at the 1, 5 and 10 % levels, respectively