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# CLIMATE CHANGE AND MORTALITY: EVIDENCE FROM 23 DEVELOPED COUNTRIES BETWEEN 1960 AND 2010

## Abstract:

This study explores the relationship between climatic change (measured by temperature rate) and mortality in 23 OECD countries during 1960–2010. By utilizing the health production framework of Becker-Grossman (2000) we indicate 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 we provide evidence that people do adapt to the most of the temperature related mortalities. We also explore the cointegration relationship between national temperatures and mortality rates. In this way we investigate whether there is a joint relation between temperature and mortality rates in the long run. Our results show evidence of the relationship between temperature increase and some cause-specific mortality rates especially in those developed countries, where the annual average temperature is over 13 degrees Celsius. There is much less evidence of cointegration in those developed countries, where the average temperature is below 5 degrees Celsius.

## Keywords:

Climate change, mortality, temperature, adaptation, fixed effect model, panel cointegration

**JEL Classification:** C10, I10, Q54

## 1. Introduction

The global climate has changed. The most recent United Nations' Intergovernmental Panel on Climate Change (IPCC) estimated that the global average temperature has increased 0.6 (+-0.2) degrees Celsius since mid-19$^{th}$ century, which most increase occurred after 1970s (IPCC 2007). Humidity and precipitation levels have also risen markedly in recent decades all over the world. It is further evident that the climate change will have a wide range of impacts on human life and health now and, especially in the future.

A vast literature document the excess mortality due to extreme heat temperature waves (e.g. Tol 2002, McMichael et al. 2006, Haines et al. 2006). For example, Hubler et al. (2008) presented that there was approximately 25 000 – 35 000 deaths due to long periods of intensive heat in the summer of 2003. Hajat et al. (2014) estimate that temperature related deaths for the UK residents' increases 250% in this century. The World Health Organization (WHO) 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 temperature-induced mortalities have welfare costs of up to 100 billion euros annually by the time period 2071-2100. On the other hand, the global warming may also decrease mortalities due to more favorable temperature environment in some parts of the world. Bosello et al. (2006) predicted that the global warming will save more than 800,000 lives annually by 2050 (see also Ackerman and Stanton 2008).

The aim of this study is to examine how climatic change (measured by temperature rates) has affected human mortality in the 23 developed countries for the period 1960-2010. 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 to mortality. The main caveat in these studies has been that the estimates are derived from short-term analysis, which does not fully control the ability of humans and societies to adapt their behavior due to climatic change. Factors such technological innovations, individual and community wealth will influence to the association between climate change and health effects (see e.g. Deschenes 2009). Further, most of the earlier studies cover only one specific country, hence, making the generalization difficult. Therefore, we argue that the best estimation of the health effects of temperature change comes from modeling the past relation between temperature and mortality across countries for relatively long-period from history. Our research question can be stated as how strongly human mortalities are associated with the global warming if the effects of adaptation are notified. To our knowledge, the adaptation effect is not systemically tested across countries in the previous studies.

We base our analysis on Becker-Grossman type of health production model (Grossman 2000). Our analysis proceeds through three stages. First, we perform a fixed effect panel regression model to explore the short-run relation between mortality and temperature rate across countries. The main advantage to use panel data models is that we can control for many potential confounding factors. We provide only some positive evidence of the relationship between temperature changes and total mortality rates. The adaptation effect

is explored by using two different sample periods. We perform panel data analysis for the sample period 1970-1989 and the sample period 1990-2010. The main finding of this approach is that the total mortality rate and some cause-specific mortality rates are related with temperature in the first sample period but that this relation vanishes almost completely in the second sample period. Our findings support Deschenes and Moretti (2009) and Barreca et al. (2016) result of the importance of adaptation effects on temperature-mortality relation.

We further examine whether the adaptation effects differ between temperature areas. To explore this we divide our data in three temperature zones. We notice that the adaptation effect seems to exist especially in those countries where the annual average temperature is below 13 degrees Celsius. Actually, in the “cold temperature zone” (annual average temperature is below 5 degree Celsius) the temperature-mortality relation vanishes completely after 1990. In those countries where the average annual temperature is above 13 degrees Celsius the temperature-mortality relation weakens but is still significant for some cause-specific mortality rates. Especially, blood and respiratory-specific mortality rates seem to increase with temperature increase in the short-run.

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

Third, we use a cointegration approach to examine the long-run relation in temperature-mortality relations. We argue that the long-run joint analysis is important, since the actions to prevent, mitigate or adopt to climate change might be costly in short-term but benefits probably occur only in the long-run. The cointegration analysis also reveals whether temperature and mortality rates are moving together in the long-run, implying whether increased future temperature increase will also increase the amount of deaths. Furthermore, there is recent evidence of the stochastic trends in temperature (Kaufmann et al. 2010) and mortality data (Edwards 2009). Using the panel dynamic ordinary least squares (PDOLS) cointegration approach, we could not find any evidence of the long-run relationship between overall mortality rate and temperature. However, we were able to show long-run cointegrating relationships between temperature and some cause-specific mortality rates. These relations are more common in the “hot temperature zone” countries than in the “medium” or “cold” temperature zone countries. Only mortalities due to infectious diseases seem to have a long-run joint relation with the temperature regardless of temperature zone.

This paper is structured as follows. Section 2 gives a theoretical framework and section 3 gives the basis of our empirical regression specification. Section 4 presents the data and section 5 gives the short-run panel fixed effect model results. In section 6 we conduct long-run estimations and panel cointegration analysis. Also, in section 6 we present the panel

fixed effect error correction model results. Finally, in section 7 we give some concluding remarks.

## 2. Theoretical context

There is a growing literature between climate change, mortality and adaptation (e.g. Kinney et al. 2008). Adaptation is defined as human adjustment in response to climate change and it effects. Deschenes (2009, p. 606) states that "…adaptation will refer to 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) present that access to health care, electricity and residential air conditioning are three most important innovations of the twentieth century that have affected temperature-mortality relation. Also, climate engineering, which means deliberate manipulation of the Earth's climate, might affect global temperature in this century (e.g. Barreca et al. 2014).

To explore the long-run relationship between mortality and temperature with the adaptation effect we utilize Becker-Grossman model of health production (see e.g. Grossman 2000). We closely follow Deschenes and Greenstone (2011) presentation. We assume that representative individual utility function consists on a consumption good C and from health or survival rate S. The utility function can be presented as

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

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

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

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 is fully solved in Deschenes and Greenstone (2011). For our purpose, it is important to note that the above model leads to raise of 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-preserving good $C_H$.

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

$$M_t = f(T, C_H, Z), \quad (4)$$

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

## 3. The empirical approach

Following the model presented above, we present the following log-linearized relation between temperature and mortality as

$$m_t = \alpha_0 + \alpha_1 temp_t + \varepsilon_t \quad (5)$$

where $m$ denotes mortality and $temp$ denotes temperature. $\alpha_0$ and $\alpha_1$ are parameters and $\varepsilon_t$ is a well-behaving error-term.

Using standard panel methods in health economics literature (e.g. Ruhm 2000) and "the new climate-economy literature" (Dell et al. 2014), the base of our estimated panel regression model takes the common form

$$m_{j,t} = \alpha + \beta temp_{j,t} + \gamma Z_{j,t} + \mu_j + \theta_{j,t} + \varepsilon_{j,t}, \quad (6)$$

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

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

## 4. Data description

We use annual information on death rates from 23 OECD countries during 1960-2011. The choice of the starting period was constrained by the data availability on some cause-specific mortality rates. The overall mortality rate, the cause-specific mortality rates and the annual temperature data are obtained from the OECD Health Database. We have selected countries as broadly as possible to cover the different type climatic environment in developed countries. The countries included are: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Netherlands New Zealand, Norway, Luxembourg, Portugal, Spain, Sweden Switzerland, the United

Kingdom and the United States. We examined the total cause-specific mortality rates (deaths/100 000 person) from 18 leading causes of death: blood, circulatory, diabetes, digestive endocrine, external, genitourinary, illness, infectious, malformations, mental, neoplasm, nervous, perinatal, respiratory, skin, suicide and tuberculosis. These specific mortality causes account the major part of all deaths.

Table 1 shows the descriptive statistics of the annual average temperature and mortality rates in 23 OECD countries. Countries are divided in three temperature zones: hot zone (average annual temperature above 13 degrees Celsius), medium hot zone (average annual temperature below 13 degrees Celsius but above 5 degrees Celsius) and cold zone (average annual temperature below 5 degrees Celsius). The hot temperature zone includes countries: Australia, Greece, Italy, Japan, New Zealand, Portugal and Spain; the medium temperature zone includes countries: Austria, Belgium, Denmark, France, Germany, Ireland, Luxembourg, Netherlands, Switzerland, the UK and the U.S.; and the cold temperature zone includes countries: Canada, Finland, Iceland, Norway and Sweden.

The highest annual mean temperature during 1960-2010 was in Australia (18.7), while the lowest in Canada (0.7). The highest total mortality rate (deaths/100 000 person) was in Portugal (1432.6) and the lowest in Germany (970.6).

Table 1. Descriptive statistics of the annual temperature and mortality rates in 23 OECD countries, 1960-2010.

| Hot temperature zone countries. annual average temperature above > 13 degrees Celsius | | | | | | |
|---|---|---|---|---|---|---|
| | Temperature | | | Mortality | | |
| Country | Mean | Max | Min | Mean | Max | Min |
| Australia | 18.7 | 19.9 | 17.6 | 1148.3 | 1623.8 | 673.3 |
| Greece | 17.7 | 19 | 16.7 | 1127.3 | 1416.7 | 819.7 |
| Italy | 15.3 | 16.8 | 13.6 | 1174.5 | 1586.2 | 699.2 |
| Japan | 14.6 | 16.1 | 13.4 | 1061.4 | 1792.2 | 613.4 |
| New Zealand | 13.1 | 14.9 | 12.2 | 1225.7 | 1581.5 | 764.7 |
| Portugal | 15.7 | 17 | 14.6 | 1432.6 | 1949.2 | 778.4 |
| Spain | 15 | 16.3 | 14 | 1120 | 1630.1 | 687.1 |
| Medium hot temperature zone countries. annual average temperature between 5-13 degrees Celsius | | | | | | |
| | Temperature | | | Mortality | | |
| Country | Mean | Max | Min | Mean | Max | Min |
| Austria | 7.2 | 9.4 | 6 | 1263.8 | 1696.4 | 761.4 |
| Belgium | 10.2 | 11.6 | 7.9 | 1286.8 | 1697.2 | 822.5 |
| Denmark | 8.3 | 9.9 | 6.6 | 1205.8 | 1497.8 | 843.8 |
| France | 11.7 | 13.6 | 9.5 | 1109.5 | 1602 | 712.5 |
| Germany | 8.4 | 9.6 | 6.9 | 970.6 | 1192.5 | 786.8 |
| Ireland | 9.8 | 10.9 | 8.7 | 1379.4 | 1772.9 | 775.4 |
| Luxembourg | 8.9 | 11 | 6.8 | 1229.7 | 1731.8 | 746.8 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Netherlands | 9.8 | 11.2 | 7.8 | 1115.3 | 1395.8 | 768.8 |
| Switzerland | 6.4 | 9.2 | 2.8 | 1085.7 | 1591.9 | 678.9 |
| UK | 9.2 | 10 | 8.2 | 1246.1 | 1656 | 790.6 |
| USA | 11.7 | 12.8 | 11 | 1170.7 | 1551.7 | 822.8 |

Cold temperature zone countries. annual average temperature below 5 degrees Celsius

| | Temperature | | | Mortality | | |
|---|---|---|---|---|---|---|
| Country | Mean | Max | Min | Mean | Max | Min |
| Canada | 0.7 | 3.4 | -2.5 | 1089.1 | 1518.9 | 717.6 |
| Finland | 2.9 | 4.8 | 0.7 | 1312 | 1942.4 | 789.1 |
| Iceland | 4.3 | 5.8 | 2.4 | 1028.7 | 1310.4 | 749.3 |
| Norway | 2.5 | 4.8 | 0.1 | 1100 | 1434.5 | 762.3 |
| Sweden | 4.2 | 5.9 | 1.8 | 1085.7 | 1446.6 | 757 |

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 of the population living in cities, is included into the regression since urban areas are vulnerable due to high concentrations of people and the influence of the urban heat effect (Kinney et al. 2008). The age variable (*old*), which denotes the % of population over 65 years, is included since 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 (*alc*) consumption variable, measured in liters per capita, is included since there is strong evidence that it increases the risk of several cause-specific mortalities (e.g. White et al. 2002). Table A1 in the appendix presents the descriptive statistics of the average annual control variables in 23 OECD countries.

## 5. Short run analysis

We begin our empirical analysis by testing whether the past temperature changes affect mortality rate changes. This is a crucial first step since environmental changes have typically lagged effect health production as presented, for example, in Menz (2011) and Schwartz (2011).

$$\Delta m_{ij,t} = \beta_0 + \beta_1 \Delta temp_{ij,t-1} + \beta_1 \Delta Z_{ij,t} + \mu_{ij} + \theta_{jt} + \upsilon_{ij,t}\,, \tag{7}$$

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

Table 2 presents the results of a variety of specifications to relationship between temperature and total mortality rates across 23 developed countries during the period 1970-2010. We have selected 1970 as our starting point for the short-run analysis due to the fact that the most of temperature increase has occurred after 1970. The main outcome

in the full sample analysis is that the average temperature has a significant and a positive effect on total mortality rate. This result is robust with respect to different specifications. Also, the estimate is insensitive to the inclusion of country specific trends and quadratic trend specifications. The fixed effect estimate in column 6 gives the best fit for temperature-mortality relation. Hence, in the rest of the analysis we use fixed effect model with additional covariates as our base specification.

Table 2. Estimation results of the lagged temperature change effects on mortality changes

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| Δtemp(-1) | .015*** | .014*** | .014*** | .014*** | .012* | .012*** | .014** | .004 |
| Δalc | | .065*** | .062*** | .062*** | | .066*** | .093*** | .013 |
| Δurb | | -.078 | -.108 | -.110 | | .039 | -.349 | .923* |
| Δune | | -.016** | -.016** | -.016 | | -.025*** | -.032*** | -.026** |
| Δold | | -.096 | -.101 | -.107 | | -.003 | -.373 | .223 |
| Countries | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 |
| Obs. | 895 | 868 | 868 | 868 | 895 | 868 | 436 | 432 |
| $R^2$ | .012 | .030 | .049 | .041 | .229 | .251 | .257 | .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 (7) is estimated with different specifications so that each column correspond to a separate regression. Specification (1) – (4) = pooled; specification (5) – (6) = fixed; specification (7) = fixed, 1970–1989; specification (8) = fixed, 1990–2010. All variables are transformed into natural logarithms. The dependent variable is $\Delta mor$, which refers to once differenced total mortality rate. Δalc = once differenced alcohol consumption, Δurb = once differenced urbanization rate, Δune = once differenced unemployment rate, Δold = once differenced age variable.*

For the full sample analysis, the results show that 1% increase in the annual average temperature leads to a modest increase in total mortality rates (.01%). To put this effect in perspective, the 1% increase in alcohol consumption leads to 5-6 times higher mortality rate increase than a similar increase in temperature rate. The effect of unemployment on total mortality is negative. This is in line with Ruhm (2000) findings that health improves when the economy temporarily deteriorates. The variables urbanization and age variables seem to have no significant effects in relation between temperature and total mortality rates in the full sample analysis.

One way to explore whether the impact of temperature change on mortality rate has changed due to adaptation is to compare the effects across sub-periods. With this respect we divide our data in two sample periods. The first period covers years 1970-1989 and the second period years 1990-2010. This is rather arbitrary choice, but here we follow Barreca et al. (2016) which states that adaptation effect due to air-conditioning and engineering has increased markedly after 1980s in the U.S. Also, splitting the sample into two same size sub-periods makes the estimation results of different sub-periods comparable and is likely to decrease the regression specification errors due to different sample sizes.

The last two columns (columns 7 and 8) in Table 2 display separate estimates for the 1970-1989 and 1990-2010 periods. As we can see, the relation between temperature and mortality is significant and positive at 5% level of significance during 1970-1989, but not significant during 1990-2010. This gives us the first evidence of the adaptation effect in temperature-mortality relation. Interestingly, also the alcohol consumption seems not to be related to overall mortality in the second sample period. On the contrary, the urbanization is highly significant and the effect of unemployment on mortality is almost the same in both sample periods.

Table 3 reports the basic fixed effect model estimation results for the cause-specific mortality rates. The regression specification is similar as fixed effect model with additional covariates in Table 2 (column 6). In the full sample analysis, there are 4 out of 17 cause-specific mortality rates that have a positive and significant relation between temperature changes. In sub-sample analysis we find 4 significant relations in the first period and only 2 in the second period. We further estimated sub-sample 2000-2010. Now, we could not find any positive and significant relation between temperature and the cause-specific mortality relations. This reflects the evidence of the adaptation effect and confirms our findings in Table 2.

Finally, we explored whether there exists asymmetry in the temperature and the cause-specific mortality rates relation. Hence, we explore whether the positive temperature changes affect cause-specific mortalities similarly as the negative changes. We find, unsurprisingly, that only the positive temperature changes seem to increase some cause-specific mortality rates. In three cause-specific mortality rates, circulatory, respiratory and tuberculosis, the increase in temperature rate increases also mortalities but not if temperature decreases.

Table 3. The effect of the lagged temperature change on the cause-specific mortality rates

| | Full sample | 1970-1989 | 1990-2010 | 2000-2010 | full sample (dltemp < 0) | full sample (dltemp > 0) |
|---|---|---|---|---|---|---|
| Circulatory | .016*** | .018*** | n.s | n.s | n.s. | .019** |
| Digestive | .028** | .021* | .062** | n.s | n.s. | n.s. |
| Illness | n.s | n.s | n.s | -.189*** | n.s. | n.s. |
| Infectious | n.s | .059** | n.s | -.156*** | n.s. | n.s. |
| Nervous | n.s | n.s | n.s | -.123** | n.s. | n.s. |
| Respiratory | .037** | n.s | .071** | n.s | n.s. | .049** |
| Suicide | n.s | n.s | n.s | .102* | n.s. | n.s. |
| Tuberculosis | .094* | .130*** | n.s | n.s | n.s. | .136* |

*Notes:. ***, ** and * denote significance at the 1, 5 and 10 % levels, respectively. The equations are estimated with country fixed effects and year fixed effects. The equation (7) is estimated for each mortality cause. The rows, where all of the estimates are not statistically significant, are omitted from the Table.*

An interesting question is whether the temperature-mortality relation is dependent on the level of temperature in a particular temperature area. Figure 1 displays changes in total

mortality and the lagged temperature changes for different temperature zones. The Figure shows that the temperature-mortality association is rather clear for the hot temperature zone countries. There seem to be much less dependence between temperature and overall mortality in the medium and the cold temperature zones.

[INSERT FIGURE 1 HERE]

Table 4 presents the estimation results for the different temperature zones. Clearly, we note the differences in the temperature-mortality relation between temperature zones during 1960-2010. The relation is not significant in the cold temperature zone, and only at 10% level of significance in the medium temperature zone. In contrast, the temperature-mortality relation is highly significant (even at 1% level of significance) in the hot temperature zone. Also, the magnitude of the effect is much higher in the hot temperature zone (.265) than in the medium hot zone (.032). Hence, in those developed countries where the average annual temperature has been over 13 degrees Celsius the effect of 1% increase in temperature leads to, on average, .265% increase in the total mortality rates. In general, there seem to be more significant relations in hot temperature zone countries and the impacts seem to be much higher level relative to the other temperature zones.

Table (4). Lagged temperature change effect on mortalities (changes)

| | Cold zone | | | Medium hot zone | | | Hot zone | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1960 - 2010 | 1970-1989 | 1990-2010 | 1960 – 2010 | 1970-1989 | 1990-2009 | 1960 - 2010 | 1970-1989 | 1990-2010 | 2000-2010 |
| Blood | n.s | n.s | n.s | n.s | n.s | n.s | 1.001*** | 1.417*** | n.s | n.s. |
| Circulatory | n.s | .019** | n.s | .005** | .102*** | n.s | .297*** | .302** | .437*** | .259* |
| Digestive | n.s | n.s | n.s | .076** | .111** | n.s | n.s | .285* | .486*** | n.s. |
| Endocrine | n.s | n.s | n.s | n.s | n.s | n.s | n.s | n.s | n.s | .576* |
| External | n.s | n.s | n.s | n.s | n.s | n.s | .298*** | .414** | .431*** | n.s |
| Genitourinary | n.s | n.s | n.s | n.s | n.s | n.s | .432*** | n.s | .576** | n.s |
| Illness | n.s | n.s | n.s | n.s | n.s | -.319* | n.s | n.s | n.s | n.s |
| Infectious | n.s | .112** | n.s | n.s | n.s | n.s | n.s | .686* | n.s | n.s |
| Malfunctions | n.s | n.s | n.s | n.s | n.s | n.s | n.s | -.852** | n.s | n.s |
| Mortality | n.s | .013** | n.s | .032* | .072*** | -.044* | .265*** | .272** | .341*** | n.s |
| Nervous | n.s | n.s | n.s | n.s | .175* | n.s | n.s | .391* | n.s | n.s |
| Perinatal | n.s | n.s | n.s | .198* | .309** | n.s | .587*** | n.s | .797** | n.s |
| Respiratory | n.s | n.s | .085* | n.s | .155* | n.s | .716*** | n.s | .275*** | n.s |
| Skin | n.s | n.s | n.s | -.453** | -.539** | -.654* | n.s | n.s | 1.774** | n.s |
| Tuberculosis | .153* | n.s | n.s | n.s | n.s | n.s | n.s | n.s | -1.341* | n.s |

*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 (7) is estimated for total mortality and each mortality cause.*

We also find evidence that the adaptation effect is present in different temperature zone data. For the cold temperature zone, we find two significant cause-specific mortality rates (circulatory and infectious) during 1970-1989, and none during 1990-2010 at 5% level of significance. For the medium temperature zone countries we find four significant relations

(circulatory, digestive, perinatal and skin) during the first sample period, but none in the second sample period at 5% level of significance. For the hot temperature zone countries the results show five significant relations (blood, circulatory, external, malfunctions) during 1970-1989 and eight (circulatory, digestive, external, genitourinary, nervous, perinatal, respiratory, skin and tuberculosis) during 1990-2010 at 5% level of significance. However, when we use sub-period 2000-2010 there is none at 5% level of significance. Hence, we may conclude that the adaptation effect is also present in hot temperature zone countries.

## 6. Long-run analysis

### 6.1 Adaptation effects

We next turn to estimate the adaptation effects more deeply. The concept of adaptation to environmental changes has been recently studied in Menz (2011). He included current and lagged air pollution variables in life satisfaction regression to explore whether people habituate to increasing level of air pollution. We follow his approach and explore the adaptation effect in temperature-mortality relation by estimating the following level-form panel fixed effect model

$$m_{ij,t} = \beta_0 + \sum_{k=0}^{n} \phi_{1ik} temp_{it-k} + \sum_{l=1}^{m} \phi_{2il} m_{it-l} + \beta_1 Z_{ij,t} + \mu_{ij} + \theta_{jt} + \upsilon_{ij,t}, \quad (8)$$

where *k* and *l* denotes lag lengths for the short-run dynamics The above dynamic fixed effects modes states that the current temperature effect on mortality is $\phi_1$ and the sum of coefficients, i.e. $\phi_1 + \phi_2 ... + \phi_n$, gives the full temperature effect on mortality. Now, if we are able to accept the null hypothesis, that $H_0 : \phi_1 + \phi_2 ... + \phi_n = 0$ we can say that there is total adaptation to temperature changes.

We have summarized our estimation results in Table 5. The number of lags are set *n* = *m* = 2. The adaptation effect on the total mortality rate (*mor*) can be rejected at 10% level of significance. Table 5 shows that there seems be full adaptation in most of the cause-specific mortality rates. There is only one cause-specific mortality rate, namely malformation, for which the full adaptation can be rejected at 5% level of significance. At 10% level of significance also for two others cause-specific mortality rates, namely nervous and infectious, the adaptation effect can be rejected.

Table 5. Mortality adaptation to temperature level changes (all countries).

| | blo | cir | dia | dig | end | ext | gen | ill | inf |
|---|---|---|---|---|---|---|---|---|---|
| temp | .03<br>(.04) | -.01<br>(.14) | .01<br>(.03) | -.02<br>(.01) | .01<br>(.03) | -.01<br>(.01) | -.01<br>(.02) | -.03<br>(.04) | -.04<br>(.03) |
| temp(-1) | .03<br>(.05) | .01<br>(.00) | -.01<br>(.03) | .02<br>(.01) | .01<br>(.02) | .00<br>(.01) | -.00<br>(.02) | .04<br>(.04) | .05<br>(.03) |
| temp(-2) | .02<br>(.04) | -.01<br>(.01) | .01<br>(.03) | -.01<br>(.01) | .04<br>(.03) | .00<br>(01) | .04<br>(.02) | .02<br>(.04) | .01<br>(.03) |
| Σtemp | .087 | -.006 | .029 | -.008 | .054 | -.003 | .020 | .031 | .026 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Prob(Σtemp>F) | 2.36 | .53 | .48 | .22 | 2.19 | .05 | .57 | 1.73 | .46 |
| (p-value) | (.13) | (.47) | (.49) | (.63) | (.14) | (.86) | (.45) | (.19) | (.50) |
| Σtemp (lags) | .054 | .009 | .014 | .009 | .047 | .003 | .032 | .062 | .067 |
| Prob(Σtemplags>F) | .97 | 1.28 | .13 | .28 | 1.77 | .04 | 1.62 | 1.73 | 3.16 |
| (p-value) | (.32) | (.25) | (.72) | (.59) | (.18) | (.83) | (.20) | (.19) | (.08) |
| Long-run effect | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | .45 |
| N | 852 | 861 | 861 | 861 | 861 | 861 | 861 | 861 | 861 |
| $R^2$ | .77 | .99 | .88 | .96 | .90 | .96 | .92 | .97 | .89 |

| Mortality cause | mal | men | mor | neo | ner | per | res | ski | sui | tub |
|---|---|---|---|---|---|---|---|---|---|---|
| temp | -.02 | -.03 | -.01 | -.00 | .02 | .02 | -.01 | .02 | -.00 | -.01 |
| (standard error) | (.03) | (.06) | (.01) | (.00) | (.02) | (.04) | (.02) | (.06) | (.02) | (.06) |
| temp(-1) | .04 | .07 | .01 | .00 | .01 | .01 | .03 | -.07 | -.01 | .07 |
| | (.03) | (.05) | (.00) | (.00) | (.02) | (.04) | (.02) | (.06) | (.02) | (.06) |
| temp(-2) | .03 | -.02 | -.00 | .00 | .02 | .02 | -.01 | -.03 | -.01 | -.06 |
| | (.03) | (.05) | (.01) | (.00) | (.02) | (.03) | (.02) | (.05) | (.02) | (.06) |
| Σtemp | .062 | .007 | .002 | .001 | .057 | .056 | -.003 | -.077 | -.029 | -.008 |
| Prob(Σtemp>F) | 2.34 | .00 | .73 | .05 | 3.70 | 1.49 | .02 | 1.19 | 1.27 | .01 |
| (p-value) | (.13) | (.92) | (.79) | (.82) | (.05) | (.22) | (.89) | (.27) | (.26) | (.91) |
| Σtemp (lags) | .078 | .040 | .011 | .002 | .035 | .033 | .008 | -.102 | -.025 | .006 |
| Prob(Σtemplags>F) | 3.95 | .37 | 3.36 | .16 | 1.54 | .54 | .11 | 2.19 | 1.05 | .001 |
| (p-value) | (.04) | (.54) | (.07) | (.68) | (.21) | (.46) | (.73) | (.14) | (.30) | (.92) |
| Long-run effect | .22 | 0 | .16 | 0 | .50 | 0 | 0 | 0 | 0 | 0 |
| N | 861 | 854 | 861 | 861 | 861 | 861 | 861 | 803 | 883 | 840 |
| $R^2$ | .85 | .93 | .98 | .97 | .93 | .92 | .93 | .86 | .97 | .94 |

*Notes: The dependent variables are natural logs of each mortality cause. The equation (8) 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 correspond to a separate regression. The long-run effects display the estimation results of equation (9). All equations include control factors (age, alcohol, urbanization and unemployment) and lagged mortality cause. All variables are transformed into natural logarithms.*

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

$$LR-effect=\frac{\sum_{k=0}^{n}\phi_{1ik}}{1-\sum_{l=1}^{m}\phi_{2il}}. \quad (9)$$

The log-run effect of total mortality is now .16, meaning that the increase in temperature by 1% leads to .16% increase in the total mortality rate in the long-run. For the cause-specific mortality rates infectious, malformation and nervous the long-run effects are .45, .22 and .50, respectively.

### 6.2 Panel cointegration approach

Before proceeding to estimate a possible cointegration relationship between temperature and mortality rate, it is necessary to investigate unit root properties of the series. Table 6 presents the panel unit root test results. For temperature rates the panel unit root test results are mixed but by using different sample sizes and temperature zones data we have reasonably evidence to presume that the temperature rates can be considered as integrated of order one. The mortality rate and the cause-specific mortality rates seem to be unit root processes. There is also a relatively recent literature that has focused to explore whether there is a unit-root in global temperature. This literature states that there is an overall evidence of the unit root properties in temperature series (e.g. Kaufmann and Stern 2002 and Kauppi et al. 2011). For mortality rates, Lee and Carter (1992) provide evidence that age-specific mortality rates contain stochastic trends. Also, Edwards (2009) specifies mortality rates as unit-root processes. Hence, in further analysis we consider both temperature and mortality rates as unit-root processes.

Table 6. Panel unit root tests for each time period and each mortality cause.

| | Levin,Lin, Chu, I(1) | Breitung, I(1) | Im,Pesaran and Chin, I(1) | ADF-Fisher, I(1) | PP-Fisher, I(1) | Hadri, I(0) |
|---|---|---|---|---|---|---|
| full sample, 1960-2010 | -1.67** | -3.75*** | -6.66*** | 126.77*** | 225.17*** | 11.08*** |
| full sample, 1970-1989 | 5.28 | 3.11 | -5.37*** | 106.68*** | 147.08*** | 3.54*** |
| full sample, 1990-2010 | 2.51 | 3.50 | .295*** | 65.51* | 189.04*** | 4.75*** |
| cold 1960-2010 | -.71 | -2.50 | -3.68*** | 30.02*** | 57.81*** | 5.56*** |
| cold 1970-1989 | 4.65 | .41 | -1.92** | 16.42*** | 48.29*** | 4.65*** |
| cold 1990-2010 | 2.27 | 2.32 | -.012 | 5.09 | 11.56 | 1.99*** |
| med.1960-2010 | 1.16 | -5.82*** | -5.84*** | 79.95*** | 143.47*** | 4.02*** |
| med. 1970-1989 | 3.65 | 2.67 | -4.78*** | 64.30*** | 36.82** | 4.28*** |
| med. 1990-2010 | 4.69 | 3.47 | -1.88** | 30.54 | 75.25*** | 3.41*** |
| hot, full sample | -1.92** | -.96 | -3.62*** | 35.83*** | 87.53*** | 5.60*** |
| hot, 1970-1989 | 1.06 | 1.68 | -2.11** | 25.96** | 61.97*** | 3.50*** |
| hot, 1990-2010 | -2.32** | -.58 | -2.86*** | 29.87*** | 102.28*** | 4.25*** |

| | Levin,Lin, Chu, I(1) | Breitung, I(1) | Im,Pesaran and Chin, I(1) | ADF-Fisher, I(1) | PP-Fisher, I(1) |
|---|---|---|---|---|---|
| Mortality | 2.09 | 3.31 | 1.10 | 37.89 | 113.75*** |
| Blood | 1.84 | 1.57 | .78 | 39.76 | 145.70*** |
| Circulatory | 1.35 | 9.92 | 4.79 | 29.53 | 48.78 |
| Diabetes | -1.35* | 1.66 | -1.94** | 60.39* | 89.66*** |
| Digestive | -.17 | 1.25 | .43 | 35.32 | 66.04** |
| Endocrine | .43 | -2.32** | -.86 | 45.54 | 69.44*** |
| External | -.78 | 2.62 | .77 | 40.51 | 74.02*** |
| Genitourinary | .27 | 2.02 | 3.32 | 25.16 | 67.96** |
| Illness | .65 | 3.28 | 1.76 | 37.64 | 71.22*** |

| | | | | | |
|---|---|---|---|---|---|
| Infectious | -1.49* | 2.14 | 1.07 | 40.87 | 84.99*** |
| Malfunctions | -.23 | 2.49 | .47 | 45.00 | 158.94*** |
| Mental | .45 | -.11 | .79 | 39.46 | 55.87 |
| Neoplasm | 4.42 | 8.02 | 7.94 | 12.32 | 30.10 |
| Nervous | -.78 | 5.44 | 2.14 | 26.03 | 44.34 |
| Perinatal | 1.84 | .36 | 2.76 | 36.76 | 90.85*** |
| Respiratory | 3.67 | 1.64 | .19 | 48.93 | 240.81*** |
| Skin | 2.09 | .1,25 | -.32 | 44.94 | 97.38*** |
| Suicide | .52 | 2.31 | 2.02 | 35.21 | 60.96* |
| Tuberculosis | 2.07 | -1.67** | 2.67 | 30.65 | 92.39 |

*Notes: ***, ** and * denote significance at the 1, 5 and 10 % levels, respectively. Levin, Lin and Chu assume common unit root process. Im, Pesaran and Chin, ADF-Fisher and PP-Fischer assume individual unit root process. Hadri test assumes stationarity. Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality.*

Given the nonstationarity of both mortality and temperature rates, the relevant question is whether there exist a long-run joint relationship between these variable, i.e. whether the linear combination of these two variables is stationary. The possible long-run relationship states that temperature and mortality rates have a common stochastic trend and, hence, these rates will move together in the long-run. This implies that an increase in temperature rates will increase also mortality rates in the long-run. The use of cointegration analysis is not novel in the climatic change literature. For example Kaufmann and Stern (2002) applied cointegration in analyzing the global climate change.

The heterogeneous multivariate panel cointegration test developed by Pedroni (1999, 2004) is utilized to explore co-movement between temperature and mortality rates. Table 7 provides the results of cointegration tests between temperature rates and the mortality rates. We use seven tests statistics to investigate whether panel data are cointegrated. The tests consist of four within-group tests and three between-group test statistics. If four to seven tests out of seven reject the null of no cointegration at 1 %, we consider a finding of a cointegration relation between temperature and mortality-specific rate. Otherwise, we conclude that there is no cointegration. The similar approach is used, for example, by Damette and Fromentin (2013). In the appendix Tables A2-A4 present cointegration tests for different temperature zones.

Table 7. Pedroni cointegration tests, whole sample.

| | Within | | | | Between | | |
|---|---|---|---|---|---|---|---|
| | Panel v | Panel rho | Panel PP | Panel ADF | Group rho | Group PP | Group ADF |
| Blood | -2.04 | -4.22*** | -5.86*** | 2.59 | -4.16*** | -5.28*** | 2.63 |
| Circulatory | 5.28*** | 2.55 | 2.78 | 6.26 | 3.55 | 3.07 | 7.14 |
| Diabetes | -2.84 | -3.45*** | -5.03*** | -0.42 | -1.04 | -2.95*** | 1.11 |
| Digestive | 1.28 | -0.81 | -2.23** | 2.13 | 0.43 | -0.79 | 2.69 |
| Endocrine | -0.08 | -3.01*** | -3.20*** | 0.61 | -1.61* | -2.38*** | 1.25 |
| External | -0.78 | -1.35 | 0.01 | 2.76 | 2.39 | 0.89 | 3.40 |
| Genitourinary | -1.30 | 1.41 | 0.51 | 4.41 | 1.55 | 1.0 | 4.90 |
| Illness | -0.14 | -0.43 | -2.00** | 1.66 | 0.42 | -0.89 | 2.26 |
| Infectious | -2.00 | -2.24** | -4.45*** | -0.24 | -0.82 | -3.63*** | 0.40 |
| Malformations | -3.11 | -0.03 | -0.99 | -0.29 | 2.94 | 1.9 | 3.7 |
| Mental | -0.55 | -0.29 | -1.01 | 2.08 | 0.86 | -0.15 | 2.61 |
| Mortality | -3.73 | -1.66** | -1.60* | 0.26 | 0.44 | 0.16 | 2.11 |
| Neoplasm | -2.19 | 0.16 | 0.25 | 3.86 | 2.61 | 2.94 | 6.01 |
| Nervous | -2.59 | 0.93 | -0.18 | 2.96 | 1.21 | -0.05 | 2.86 |
| Perinatal | 3.17*** | 0.12 | -1.42* | 4.20 | 0.27 | -0.74 | 3.83 |
| Respiratory | -0.69 | -13.65*** | -13.28*** | -0.77 | -11.23*** | -13.10*** | 0.96 |
| Skin | 0.97 | -7.09*** | -6.63*** | -2.50*** | -4.49*** | -5.77*** | -1.57* |
| Suicide | -1.51 | -2.76*** | -2.74*** | -0.82 | -1.08 | -1.56* | 0.22 |
| Tuberculosis | 0.06 | -5.41*** | -6.32*** | 0.11 | -0.97 | -2.95*** | 1.06 |

*Notes: ***, ** and * denote significance at the 1, 5 and 10 % levels, respectively. The null hypothesis is that there is no cointegration between temperature rate and each of the cause-specific mortality rate. The specification of the test regression is chosen separately for each mortality cause. The panel within statistics are weighted statistics.*

We are able to reject the null of no cointegration at 1 % significance level for only three cause-specific mortalities, namely blood, respiratory and skin, when we look at the full sample. When we divide the sample into three temperature zones, we find cointegration between the temperature and cause-specific mortality rates in the hot temperature zone for blood and respiratory, in the medium temperature zone for malformations and respiratory, and in the cold temperature zone for blood- and skin-related mortalities. Based on the results we can conclude that the cointegration relationship is temperature zone dependent.

Based on cointegration tests we can estimate the long-run relationship between the temperature and mortality-causes. We apply panel dynamic ordinary least squares (PDOLS) (Saikkonen 1991, Stock and Watson 1993) to equation (5) and estimate the cointegrating equation and the associated coefficients. We choose PDOLS as our estimation method, because it has been shown to be asymptotically efficient estimator for cointegrated panels (Baltagi 2008: 294). The results are provided in Table 8.

Table 8. Estimated regression coefficients and levels of significance of the cointegration equations.

| | whole sample | hot zone | medium hot zone | cold zone |
|---|---|---|---|---|
| Circulatory | n.s. | -0.559*** | n.s. | n.s. |
| Illness | n.s. | n.s. | 0.641*** | n.s. |
| Infectious | 0.209*** | n.s. | 0.953*** | 0.090** |
| Mental | n.s. | 4.052*** | n.s. | n.s. |
| Neoplasm | n.s. | 0.355*** | n.s. | n.s. |
| Nervous | n.s. | 1.150*** | n.s. | n.s. |
| Respiratory | n.s. | n.s. | 0.332*** | n.s. |
| Skin | n.s. | n.s. | n.s. | 0.269** |
| Suicide | n.s. | n.s. | -0.182** | n.s. |

*Notes: ** and * denote significance at the 1 and 5 % levels, respectively. The selection of optimal leads and lags specification is done using Schwarz information criteria with maximum of 1 leads and lags. The estimation period is 1960–2010. The rows, where all of the estimates are not statistically significant, are omitted from the Table.*

For the full sample analysis, we find that temperature is positively and significantly associated with only infectious-specific mortality rate. The long-run relation can also be seen in Figure 2, where we have depicted the natural logarithms of the annual temperature and infectious-related mortality rates in 23 OECD countries between 1970 and 2010.

[INSERT FIGURE 2 HERE]

The estimates for the hot temperature zone are significant and positively associated to mental, neoplasm and nervous related mortalities. The association was significant but negative with respect to circulatory-related mortalities. The unexpected negative signs in statistically significant PDOLS estimates might result from negative trends of the cause-specific mortality time series. The amount of circulatory-related mortalities has decreased in the hot temperature zone countries over the sample period but the temperature has increased. The negative relation between temperature and some cause-specific mortality may also reflect that the global warming might affect positively health production. In some parts of the world climate change leads to more favorable temperature environment with respect to health outcomes. For example, if winter becomes milder, in some countries, there is probably less mortalities due to myocardial infections and strokes.

For the medium temperature zone higher temperatures were significantly associated with higher illness, higher infectious and higher respiratory related mortality and negatively related to suicide mortality. For the cold temperature zone higher temperature resulted higher infectious- and skin-related mortalities.

To sum up our cointegration results so far, we may conclude that the most frequent cause-specific mortality rates that share a common trend with temperature is infectious diseases. This support Tol (2002) who emphasizes that vector-borne diseases, which account for 17% of the estimated global burden of all infectious diseases, will increase significantly when temperature level rises (see also Haines et al. 2006). Furthermore, he notifies that the non-vector borne infectious diseases are increasing with climate change.

The significance of the respiratory-specific mortality results in the medium temperature zone is in line with Barreca (2012) who presents that the exposure of extreme temperatures levels increase the risk of mortality through respiratory systems. Also, our finding of the skin-related deaths in association with climate change in the cold temperature zone is in line with previous literature (see e.g. Bharath and Turner 2009)

The high magnitude effect with respect to temperature and mental cause-specific mortality rate support Cunsolo Willox et al. (2013) result that the climatic change has also serious consequences for mental health. Every year, especially in hot temperature zone countries, a large number of people are hospitalized in association to elevated temperatures due to mental health problems. Hansen et al. 2008 found that heat waves exacerbates symptoms of dementia, depression and anxiety and are associated with a 64 per cent increase in admissions to psychiatric hospitals. Further, they find that admissions for individuals with post-traumatic stress disorder, obsessive compulsive disorder, and panic disorder increases by nearly 10 per cent during the period the intense heat.

We also show that temperature-mortality relation is more common in hot temperature zone, i.e. in those developed countries where the annual average temperatures have been above 13 degrees Celsius. There is much less evidence of cointegration in those developed countries, where the average temperatures have been below 5 degrees Celsius. Our results, hence, imply that the temperature-related mortality effects are very much temperature area dependent.

For those cause-specific mortality rates where the cointegration between temperatures can be found, we can also estimate an error-correction presentation. We estimate the following dynamic panel fixed effects error-correction model

$$\Delta m_{ij,t} = \beta_0 + \gamma_{ij} ECT_{ij,t-1} + \sum_{k=0}^{n} \phi_{1ik} \Delta temp_{it-k} + \beta_1 \Delta Z_{ij,t} + \mu_{ij} + \theta_{jt} + \upsilon_{ij,t} \ , \qquad (10)$$

where the long-run cointegration relation or, in other words, error correction term, is as

$$ECT_{ij,t} = m_{ij,t} - \alpha_{1ij} - \alpha_{2ij} temp_{ij,t} \qquad (11)$$

.

The ECT is the disequilibrium term predicting how far the predicted relations are from the long-run equilibrium levels. In estimation we use the residual series obtained from PDOLS-estimation. We have discarded the lagged mortality rates from the estimated model because of the possibility of the endogeneity problem due to collinearity between the lagged error-correction term and the lagged dependent variable.

The results for the dynamic fixed-effect error-correction model are presented in Table 9. We have estimated this equation using different lag structures and different combinations of explanatory variables for robustness checks. We have selected the lag length *n* = 1. The error correction terms (γ) have an expected negative signs and are significant at the 1% level for all specifications. The error-correction term gives the speed of adjustments to the long-run equilibrium level. The magnitude of the error-correction term varies between [-.15 -.88]. Overall, these results suggest that a 1% deviation from the temperature-mortality

long-run equilibrium level will approximately lead to [.15, .89]% change in the cause-specific mortality rates during the following year.

Table (9). Panel fixed effects error correction models for whole sample, hot zone, medium hot zone and cold zone.

| | Whole sample | Hot zone | | | | Medium hot zone | | | | Cold zone | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Δinf | Δcir | Δmen | Δneo | Δner | Δill | Δinf | Δres | Δsui | Δinf | Δski |
| Intercept | -0.017 | -0.018*** | -0.012 | 0.002 | 0.012 | -0.022* | -0.006 | -0.013 | -0.002 | 0.006 | -0.001 |
| ECT(t-1) | -0.426*** | -0.331*** | -0.150*** | -0.436*** | -0.339*** | -0.238*** | -0.392*** | -0.419*** | -0.614*** | -0.876*** | -0.346*** |
| Δtemp(t-1) | 0.033* | 0.394*** | 0.363 | 0.037 | 0.203 | 0.015 | 0.067 | 0.037 | 0.043 | 0.079*** | -0.035 |
| $R^2$ | 0.295 | 0.525 | 0.314 | 0.475 | 0.394 | 0.281 | 0.370 | 0.576 | 0.413 | 0.525 | 0.513 |
| Long run effect | 0.062 | 0.198 | 0.786 | 0.203 | 0.285 | 0.144 | 0.503 | 0.101 | -0.139 | 0.003 | 0.124 |
| n | 1006 | 306 | 306 | 308 | 308 | 475 | 473 | 473 | 500 | 225 | 187 |

*Notes: ***, ** and * denote significance at the 1, 5 and 10 % levels, respectively. The estimation results of equation (10). Each column correspond to a separate regression. All equations include control factors (age, alcohol, urbanization and unemployment). The equations are estimated with country fixed effects and year fixed effects. The error correction term $ECT_{t-1}$ corresponds to lagged residual term of equation (11).*

On the basis of PDOLS estimates and the above error-correction presentations, we can compute the long run impacts of temperature changes on each cause-specific mortality rates. For example, the impact of infectious-related deaths for the full sample is computed by summing the short-run effect (.033) and the error-correction estimate (-.426) multiplied by the PDOLS estimate with the negative sign (-.209). Hence, we find that 1 % increase of annual average temperature increases, for example, the infectious-related mortality by .062% in the 23 OECD countries. For the hot temperature zone countries there is no long-run association between temperature and infectious-related deaths. For the medium temperature zone countries the same effect is, on average, .503% and for the cold temperature zone countries, .003%.

In hot temperature zone the mental health related mortality seems to be very sensitive to the temperature increase, since the long-run effect for 1% increase in temperature is .786% in mental health deaths. There are also rather high long-run effects for circulatory- (.198), neoplasm- (.203%) nervous-specific (.286) mortality rates. In the medium temperature zone, the infectious mortalities are the most sensitive to temperature increase. There is also a modest increasing mortality effects for illness (.144), and respiratory-related (.503) deaths in the long-run. Interestingly, suicide-related deaths are negatively related to temperature changes in the medium temperature zone. However, the effect is rather small (-.139).

For the cold temperature zone, the significant long-run relation is found for infectious- and skin-related deaths. The long-run effect for skin-related deaths is .125%. In general, the long run effects are, on average, much larger and they have more variation for the hot and medium temperature zone countries than in the cold temperature zone countries.

## 7. Concluding remarks

Climate change will affect well-being in multiple ways in this century. The latest evaluation by IPCC (2007) predicted that global temperature will increase between 1.8 and 4.0 degrees Celsius by 2100. Despite the large amount of research, the accurate estimation of the temperature effects on mortality is rather complex task. First, the forecasts of an increase in global average temperature vary a lot indicating uncertainty about the sensitivity of the climatic system. Second, the human adaptation, climate engineering and mitigation effects are in an important role when analyzing temperature-mortality relation.

We contribute the previous literature in many important ways. First, we perform our investigation in a several country context, which allows us to make more convincing conclusions about the climate change effect on the mortality rates. Second, we use both short-run and long-run analysis to emphasize the relation between temperature change and cause-specific mortality rates. Third, we take into account the adaptation effect. More specifically, we provide clear evidence of adaptation effect in temperature-mortality relation in 23 developed countries during the time period 1970-2010. Our analysis shows that humans have been quite adaptive to the climatic change, and that there are only some diseases that have clear effects on mortalities when the temperature increases. The results are robust in the sense that temperature and mortalities relations do not change even if we take into account also the socio-economic factors.

As a policy recommendation we argue that when analyzing climate change effects on health production it is crucial to take the adaptation effects into account. Further, it is crucial to recognize that the adaptation effect might differ in different temperature zones. Also, the adaptation might be expensive, and hence especially, in the poorer countries the full benefits of the adaptation will not be possible.

For the future research we suggest that to have a good understanding climatic change effects on public health we should also consider the effects of temperature variations and temperature thresholds on cause-specific mortality rates. Furthermore, since air pollution usually increases jointly with temperature it would be necessary to take this joint behavior into account when predicting the climate change effects on health production. Further, since humans are able to adapt to changing in climate conditions it is crucial to include the possible climatic engineering and/or the adaptation variables into the analysis to explore the long-run joint relations between climate change and health effects. These important aspects are, however, left for future research.

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*** |
| 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*** |

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

Table A2. Pedroni cointegration tests, hot zone.

| | Within | | | | Between | | |
|---|---|---|---|---|---|---|---|
| | Panel v | Panel rho | Panel PP | Panel ADF | Group rho | Group PP | Group ADF |
| Blood | 0.46 | -1.83** | -2.44*** | 1.67 | -2.69*** | -3.54*** | 1.30 |
| Circulatory | 0.346 | 1.684 | 1.968 | 3.331 | 2.163 | 1.578 | 3.527 |
| Diabetes | -0.472 | -1.110 | -1.917** | 0.405 | -0.310 | -1.742** | 0.953 |
| Digestive | 2.976*** | -0.243 | -0.728 | 1.378 | 0.716 | 0.339 | 2.448 |
| Endocrine | -0.257 | -0.651 | -1.250 | 0.021 | 0.669 | -0.426 | 0.733 |
| External | -1.145 | 1.162 | 1.122 | 2.000 | 1.655 | 1.499 | 2.661 |
| Genitourinary | -0.637 | 1.1101 | 0.646 | 1.908 | 1.378 | 0.971 | 2.344 |
| Illness | 1.109 | -0.708 | -1.400* | 1.068 | 0.477 | 0.486 | 2.107 |
| Infectious | -1.340 | 0.311 | -1.438* | -0.650 | 1.415 | -0.846 | -0.072 |
| Malformations | -1.190 | -1.105 | -1.978** | 2.275 | -2.317** | -2.893*** | 1.735 |
| Mental | -1.042 | -2.173** | -2.385*** | -1.091 | -0.831 | -1.733** | -0.418 |
| Mortality | 6.904 | -2.048** | -2.230** | 0.379 | -0.945 | -1.843** | 1.636 |
| Neoplasm | -0.903 | 1.006 | 0.394 | 1.541 | 2.325 | 1.342 | 2.688 |
| Nervous | -2.064 | 1.342 | 1.093 | 3.382 | 1.018 | 0.915 | 3.300 |
| Perinatal | 4.824*** | -0.636 | -1.101 | 0.907 | -0.252 | -0.767 | 1.040 |
| Respiratory | -0.806 | -5.826*** | -6.492*** | -0.614 | -5.501*** | -6.909*** | -0.990 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Skin | 1.481* | -3.967*** | -4.139*** | -1.599* | -2.369** | -3.225*** | -0.784 |
| Sui | -0.0347 | -1.698** | -2.226** | 0.103 | -1.178 | -2.260** | 0.444 |
| Tuberculosis | 3.433*** | 0.723 | 0.467 | 2.45 | 1.360 | 1.282 | 3.494 |

*Notes: ***, ** and * denote significance at the 1, 5 and 10 % levels, respectively. The null hypothesis is that there is no cointegration between temperature rate and each of the cause-specific mortality rate. The specification of the test regression is chosen separately for each mortality cause. The panel within statistics are weighted statistics.*

## Table A3. Pedroni cointegration tests, medium hot zone.

| | Within | | | | Between | | |
|---|---|---|---|---|---|---|---|
| | Panel v | Panel rho | Panel PP | Panel ADF | Group rho | Group PP | Group ADF |
| Blood | -0.641 | -1.173 | -0.916 | 2.002 | -1.293* | -1.776** | 1.345 |
| Circulatory | 6.253*** | 2.600 | 2.449 | 5.078 | 2.750 | 2.884 | 5.732 |
| Diabetes | 0.488 | -2.665*** | -2.620*** | -0.396 | -1.143 | -1.733** | 0.366 |
| Digestive | 0.214 | 0.476 | -0.366 | 1.462 | 0.716 | -0.155 | 1.533 |
| Endocrine | 1.025 | -2.515*** | -2.269** | 0.106 | -1.347* | -1.793** | 0.531 |
| External | -0.241 | 1.830 | 0.580 | 1.514 | 2.635 | 1.292 | 2.043 |
| Genitourinary | -0.774 | 1.154 | 0.685 | 3.306 | 0.628 | 0.368 | 3.459 |
| Illness | -0.171 | 0.349 | -0.434 | 0.812 | 0.798 | -0.349 | 0.956 |
| Infectious | -1.219 | -1.966** | -2.586*** | 0.104 | -0.645 | -2.073** | 0.651 |
| Malformations | 5.745*** | -3.662*** | -3.628*** | 0.722 | -3.427*** | -4.059*** | 1.042 |
| Mental | -1.012 | 0.425 | -0.252 | 0.915 | 0.921 | 0.306 | 0.830 |
| Mortality | 11.114*** | -1.379* | -1.836** | 3.678 | -2.043** | -3.071*** | 2.673 |
| Neoplasm | -1.742 | -0.579 | -0.204 | 2.444 | 1.836 | 2.961 | 4.908 |
| Nervous | -1.507 | -0.288 | -1.320* | 1.021 | 0.507 | -0.872 | 1.426 |
| Perinatal | 0.618 | 2.077 | 1.474 | 3.937 | 2.012 | 1.427 | 3.800 |
| Respiratory | -0.381 | -13.050*** | -11.713*** | -1.403* | -10.491*** | -11.786*** | 0.936 |
| Skin | -0.107 | -1.703** | -2.180** | -1.018 | -0.887 | -1.877** | -0.656 |
| Sui | -1.160 | -0.917 | -0.575 | 2.006 | 0.378 | 0.157 | 2.400 |
| Tuberculosis | 6.357*** | -1.466* | -2.320** | 2.801 | -2.629*** | -3.388*** | 2.715 |

*Notes: ***, ** and * denote significance at the 1, 5 and 10 % levels, respectively. The null hypothesis is that there is no cointegration between temperature rate and each of the cause-specific mortality rate. The specification of the test regression is chosen separately for each mortality cause. The panel within statistics are weighted statistics.*

## Table A4. Pedroni cointegration tests, cold zone.

| | Within | | | | Between | | |
|---|---|---|---|---|---|---|---|
| | Panel v | Panel rho | Panel PP | Panel ADF | Group rho | Group PP | Group ADF |
| Blood | -1.105 | -8.157*** | -7.853*** | -1.267 | -5.766*** | -6.546*** | -0.092 |
| Circulatory | 4.518 | 0.147 | -0.429 | 2.095 | 0.981 | 0.449 | 2.633 |
| Diabetes | -1.682 | -1.181 | -1.432* | -0.521 | -7.833*** | -5.577*** | -1.098 |
| Digestive | -0.943 | -0.442 | -0.796 | 1.347 | -0.435 | -1.012 | 1.500 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Endocrine | -0.542 | -2.080** | -1.988** | 0.753 | -2.256** | -1.931** | 1.035 |
| External | 0.341 | -1.838** | -2.791*** | 0.603 | -0.730 | -1.779** | 1.122 |
| Genitourinary | -0.864 | 0.016 | -0.613 | 2.296 | 0.783 | 0.484 | 2.607 |
| Illness | -0.358 | -2.844*** | -3.697*** | -1.119 | -2.170** | -3.869*** | -0.733 |
| Infectious | -0.830 | -2.796** | -4.277*** | -0.532 | -2.461*** | -3.710*** | -0.025 |
| Malformations | -1.413 | -1.184 | -1.236 | 1.303 | -1.36351* | -1.2318 | 1.749 |
| Mental | 1.143 | -1.756** | -2.061** | 1.637 | -0.601 | -1.70** | 2.096 |
| Mortality | 9.292*** | -1.993** | -2.245** | 0.819 | -1.620* | -2.399*** | 1.336 |
| Neoplasm | -0.952 | 0.127 | 0.276 | 2.428 | 0.121 | 0.328 | 2.435 |
| Nervous | -0.526 | 0.421 | -0.109 | 2.251 | 0.640 | 0.108 | 2.431 |
| Perinatal | -1.739 | -0.507 | -1.109 | 0.919 | -0.587 | -1.059 | 1.480 |
| Respiratory | 0.130 | -2.498** | -1.768** | 1.544 | -2.472*** | -1.747** | 2.053 |
| Skin | -1.150 | -6.288*** | -5.936*** | -1.594* | -3.362*** | -4.688*** | 0.338 |
| Suicide | -1.278 | -1.950** | -2.469*** | 0.475 | -0.392 | -0.791 | 0.916 |
| Tuberculosis | -1.579 | -1.273 | -1.883 | 0.519 | -2.028 | -2.153 | 0.231 |

*Notes: ***, ** and * denote significance at the 1, 5 and 10 % levels, respectively. The null hypothesis is that there is no cointegration between temperature rate and each of the cause-specific mortality rate. The specification of the test regression is chosen separately for each mortality cause. The panel within statistics are weighted statistics.*

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