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Estimating the Impacts of Climate Change on Mortality in OECD Countries*

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Abstract

The major contribution of this study is to combines both climatic and macroeconomic factors simultaneously in the estimation of mortality using the capital city of 22 OECD countries from the period 1990 to 2008. The empirical results provide strong evidences that higher income and a lower unemployment rate could reduce mortality rates, while the increases in precipitation and temperature variation have significantly positive impacts on the mortality rates. The effects of changing average temperature on mortality rates in summer and winter are asymmetrical and also depend on the location. Combining the future climate change scenarios with the estimation outcomes show that mortality rates in OECD countries in 2100 will be increased by 3.77% to 5.89%.

Keywords: Climate change; Mortality; Panel data model.

1. Background

The Intergovernmental Panel on Climate Change [1] has estimated that global damage from climate change during the period from 1991 to 2005 was about US$1,190 billion where the areas most damaged have been crops, fishery, water resources, and human health. IPCC [1] also pointed out that the frequency and strength of heat waves will become more serious which may place more people in a higher risk environment.

Many studies have focused on the impact of climatic factors on the mortality rate. In terms of environmental variables, the changes in global surface temperatures induced by greenhouse gas concentrations have an insignificant influence on mortality [2-6], and the climatic factors have a more significant impact on mortalities than concentrations of air pollution [7]. In addition, locations or latitudes with a combination of climate conditions may have diverse effects on mortality. For a warm area, weather that becomes colder may give rise to a higher mortality risk than weather that becomes hotter, and vice versa [8-12]. The effect of such a change of temperature on mortality in alternative locations may exhibit asymmetry which will be investigated in this study.

The effect of minimum temperature on mortality is greater than that of maximum temperature [7, 11]. Here, it is worth notice that some studies [13, 14] thought that the average temperature is more appropriate in explaining mortality, even the average temperatures in the summer and winter seasons have more significant influences on mortality than those in the spring and autumn [15-17]. As for the dew point temperature, it has an obvious positive impact on mortality [18].

Not only does the temperature level affect mortality, but the effect of temperature variation on mortality may be more significant [19]. Under the situation where there is a large variation in temperature, the aging of the population results in a more rapidly increasing velocity of mortality [20], because the ability of elderly people to physically respond to extreme weather conditions is much reduced. For instance, using diurnal temperature variations in Shanghai during the period from 2000 to 2004, an increase in diurnal temperature variations of 1 ℃ induces total mortality to increase by 1.37% [21].

The effects of extreme weather events such as heat waves have threatened human life in some particular areas. High temperatures on successive days affect mortality for certain [7, 22-26]. The higher the number of such days, the higher the resulting mortality. They also found that older people are more easily subjected to higher mortality risk.

On the other hand, macroeconomic conditions including national income and health are the key indices affecting mortality. National income is positively correlated with national health [27-39]. In addition, the influence of national economic structure on national health levels indicated that the reason why countries increased their healthcare spending to improve health was because of the growth in national income brought about by economic growth, and not because of the differences in economic structure between countries [40-42]. [43] compared African countries with Organization for Economic Cooperation and Development (hereafter OECD) countries, and found that while each state government had different policies on education, healthcare and the environment, there was evidence in each country of a transformation of increased national income into increased expenditures on healthcare.

Because a country's unemployment rate has a very close relationship with that country's socio-economic background, it is viewed as a good indicator of economic change. The correlation between unemployment rates and mortality showed that increases in the unemployment rate lead to increased mortality and crime rates, and a deterioration in health [44-50].

Based on these analyses of literature reviews on the issue of mortality, both climatic and macroeconomic factors play important roles. However, all of these studies either evaluate the effects of climatic or macroeconomic factors on mortality separately which may result in biased estimates due to the omission of important variables. Therefore, the main purpose of this study is to simultaneously investigate the effects of climatic and macroeconomic factors on mortality in the capital cities of 22 OECD countries as well as to predict the potential effects of climate change.

There are two major reasons for selecting these capital cities in 22 OECD countries as the research target. The first is that using the capital city may well represent the economic condition of the country and data on climatic conditions as well as the mortality rate is relatively easy to collect and match. The second reason is that these capital cities in 22 OECD countries locate in different latitudes which could be examined the effects of temperature change on mortality rate in different seasons and locations. For instance, the extreme heat wave events in Europe in summer have increased the number of deaths which implies that the increasing temperature on mortality rate in Europe in summer season may be significantly higher. The remainder of this paper is organized as follows. In Section 2, we discuss the mortality function and data sets are described in Section 3 while the econometric methodology and empirical results are introduced and explained in Section 4. The potential impacts of climate change on mortality rates in OECD countries are simulated in Section 5, and the concluding remarks are presented in Section 6.

2. Mortality Functions

Although the various studies that have discussed the relationship between macroeconomic conditions and mortality use a variety of methods including descriptive, cross-crossover or cross-country and time-series approaches to estimate the relationships between climatic factors and mortality, such studies do not consider both climatic and macroeconomic factors simultaneously. Therefore, the mortality function in this study will be built by taking account of these two factors simultaneously.

The mortality functions

The mortality functions used in this study will be established in order to explicitly comprehend the relationships between climatic factors and macroeconomic conditions and mortality. Three characteristics are addressed in relation to these mortality functions. The first one is that the impact of both the climate and macroeconomic factors on mortality could be examined at the same time as is shown in Model I. The second one is that seasonal dummy variables and cross-multiplication with temperature are taken into consideration to examine how temperature in different seasons will affect the mortality that is shown in Model II. The third one is that summer and regional dummy variables, as well as terms multiplied by temperature, are simultaneously considered in the mortality function to investigate whether mortality rates are higher in European countries in summer than in non-European countries as shown in Model III. Each dependent and independent variable is transformed into logarithmic form to better express the non-linearity of mortality and climate and the macroeconomic conditions. The mortality functions could be specified as follows:

Model I

$$Mor_{it} = \alpha_0 + \alpha_1 * temp_{it} + \alpha_2 * prec_{it} + \alpha_3 * dew_{it} + \alpha_4 * \mathrm{var}\, temp_{it} + \alpha_5 * GDP_{it} + \alpha_6 * unemp_{it} + \varepsilon_{it} \quad (1)$$

Model II

$$Mor_{it} = \beta_0 + \beta_1 * temp_{it} + \beta_2 * prec_{it} + \beta_3 * dew_{it} + \beta_4 * \mathrm{var}\,temp_{it} + \beta_5 * GDP_{it} + \beta_6 * unemp_{it} + \beta_7 * Summer + \beta_8 * Fall + \beta_9 * W\,\mathrm{int}\,er + \beta_{10} * Summer * temp_{it} + \beta_{11} * Fall * temp_{it} + \beta_{12} * W\,\mathrm{int}\,er * temp_{it} + \varepsilon_{it}$$

(2)

Model III

$$Mor_{it} = \gamma_0 + \gamma_1 * temp_{it} + \gamma_2 * prec_{it} + \gamma_3 * dew_{it} + \gamma_4 * \mathrm{var}\,temp_{it} + \gamma_5 * GDP_{it} + \gamma_6 * unemp_{it} + \gamma_7 * Summer + \gamma_8 * region + \gamma_9 * Summer * temp_{it} + \gamma_{10} * Summer * region * temp_{it} + \varepsilon_{it}$$

(3)

where

i the index of the i[th] capital city of 22 OECD countries,

t the index of the time period from 1990 to 2008,

Mor_{it} monthly mortality rate,

$temp_{it}$ monthly average temperature,

$prec_{it}$ monthly precipitation,

dew_{it} monthly average dew point temperature,

$\mathrm{var}\,temp_{it}$ monthly variance of temperature,

GDP_{it} real gross domestic product per capita,

$unemp_{it}$ monthly unemployment rate,

summer summer dummy variable,

fall fall dummy variable,

winter winter dummy variable,

region regional dummy variable, 1 for European countries while 0 otherwise.

3. Data Description

To estimate equations (1) to (3), data on all independent and dependent variables need to be collected. Based on the studies [4, 13, 21, 51], mortality is defined as that from all-causes and non-accidental death. Due to the different demographic structures of each country, if the study uses mortality data without taking population structures into account, the results may be unable to reflect the true situation. For this reason, this study takes the crude mortality rate, that is, the number of deaths in each country divided by the mid-month average total population of each city and multiplied by 1,000. The monthly numbers of deaths and total populations of the 22 OECD countries studied are obtained from the statistical bureaus in each country.

Real GDP per capita based on 2,000 US dollars is viewed as a measure of the national economic development index. Data on real GDP and the unemployment rate are obtained from the OECD database. Mean temperatures and the amounts of precipitation are obtained from the International Research Institute for Climate and Society. We transform data on the daily average temperatures and dew points obtained from the National Climatic Data Center into monthly temperature variations and mean dew points. The aforementioned temperature indices are expressed in Fahrenheit.

The above data are all monthly data during the 1990-2008 period and relate to the capital cities of the 22 OECD countries under study. The 22 OECD countries include Austria, Australia, Belgium, Canada, Switzerland, Germany, Denmark, Spain, Finland, France, Greece, Hungary, Italy, Japan, Korea, the Netherlands, Norway, Poland, Portugal, Sweden, the United Kingdom, and the United States.

The statistical descriptions for all the variables are shown in Table 1 while the detailed statistical data for each variable are shown in the appendices. Table 1 shows the average mortality rate for the 22 capital cities of OECD countries to be 2.006 while the mortality ranges from 0.988 to 4.057. The crude mortality rate in Hungary is the highest of the 22 OECD countries while that for the USA is the lowest as shown in Appendix I. Several countries' crude mortality rates have been selected as shown in

Figure 1. This graph shows that the mortality rates vary in different countries, which indicates that the characteristics of a country, such as its economic development, may affect its mortality. The graph also shows that the mortality rates for some countries have higher peaks in winter while Europe's mortality rate is higher in the summers of 2003, 2006, and 2007 than in other seasons, which implies that the location of a country is one of the factors affecting mortality rates.

Table 1 also shows that the average GDP per capita in the 22 OECD countries is about US$ 2363.148, which is higher than the global average. The detailed GDP per capita for the 22 OECD countries is shown in Appendix II. Norway has the highest GDP per capita while Poland has the lowest among the 22 OECD countries. The average unemployment rate for the 22 OECD countries is about 7.412% which is higher than that for developing counties. As the economies become more highly developed, the unemployment rate may remain at a higher level as compared with developing countries. We can see that the unemployment rate in Poland, Germany, Spain, Finland, and France reaches 5%, whereas Japan and Korea have the lowest unemployment rates as shown in Appendix III. With regard to the standard deviation, the results show that the variability measure in Germany, France, Greece, Belgium, Canada, and Italy reaches 5, while Poland and Switzerland have lower standard deviations than the other countries.

Appendix IV shows that the average monthly temperatures in Greece, Italy, Portugal, and Spain are as high as 60°F, and so we can see that most of the countries having higher average monthly temperatures are located in Southern Europe. Moreover, heat waves cause more serious damage in Southern Europe. In Canada, Finland, Hungary, Korea, and the USA, the standard deviation of monthly average temperature is higher which means that these countries experience more significant changes in monthly average temperatures over the nineteen-year period. The average monthly temperature variations in Austria, Belgium, Canada, Switzerland, Germany, Finland, France, Korea, Norway, Poland, Sweden, and the USA are higher than in other countries such as Canada, Norway, and the USA as shown in Appendix V. Large degrees of variation in temperature may affect mortality rates. Finally, the average monthly precipitation in Japan, Korea, and Denmark exceeds 100mm, and Korea and Japan exhibit volatile variation in precipitation as shown in Appendix VI.

4. Results

To estimate equations (1) to (3), monthly data sets for mortality and climatic and macroeconomic factors need to be established. The panel model estimation approach is adopted since such data sets are panel data sets. To implement equations (1) to (3), all variables have to meet the requirement of stationarity. Therefore, a panel unit root test [52] will be implemented first. Later, both the fixed effects model and random effects model will be applied to the estimation of equations (1) to (3).

We use the panel LM test [52] to test the stationarity of the six variables, and the results are reported in Table 2. Based on the empirical outcomes of the LM panel unit root test results with no break, one break, and two breaks, we find that the LM unit root test with no break and one break support the nonstationarity of real GDP per capita and the unemployment rate, but the LM unit root test with two breaks supports the stationarity of all series at the 1% significance level. Hence, in the case of the panel LM unit root test with two breaks, all of the series are stationary.

The empirical results for Models I to III are presented in Tables 3, 4, and 5. The Hausman test results displayed in Tables 3 to 5 indicate that the fixed effects model is accepted. The estimation outcome of Model I in Table 3 shows that the average temperature has significantly negative effects on the mortality rate which is consistent with the findings of Dessai, Donaldson et al., and Pattenden et al. [2, 12, 53, 54]. The amounts of precipitation have significantly positive effects on the mortality rate which is also verified by Ebi et al.'s finding [55]. The effects of average dew point temperature on the mortality rate are significantly positive which is similar to the finding of Guest et al. [18]. With regard to temperature variation, this is shown to have a significantly positive effect on the mortality rate which is the same result obtained by Applegate et al., Bull and Morton, Conti et al., Ellis et al., Greenberg et al., Jones et al., and Schwaetz [19, 20, 22, 23, 56-60]. By comparing the degree of influence for all climatic factors, we find that temperature variation caused a more significant increase in the mortality rate than the other climatic factors.

In terms of macroeconomic conditions, real GDP per capita has a significantly negative influence on the mortality rate which indicates that higher income results in lower mortality. Such an estimation outcome is consistent with the findings of Breault, Buckley et al., Burr, Chung and Huang, Gerdtham, Gunnell et al., Huang and Huang, Mcleod et al., Neumayer, and Smith [30-39]. On other hand, the unemployment rate influences the mortality rate both significantly and positively which is similar to the findings of Brenner, Brenner and Moonry, Platt, and Stack [45-50].

For the estimation outcome of Model II in Table 4, we perceive that there exists a correlation between seasonal temperature and the mortality rate. Firstly, the estimated parameters for these seasonal dummy variables are different, which indicates that the mortality rate varies with the seasons. Secondly, the effects of the Summer, Fall, and Winter seasons on the mortality rate are 0.555, 0.031, and 0.060, respectively, which shows that mortality rates in the Summer and Winter seasons are higher than in the other two seasons.

Subsequently, Table 4 also shows the asymmetric effects of temperature on the mortality rates in different seasons. Because the coefficients of cross-multiplication with seasonal dummy variables and temperature are significant, the effects of average temperature on the mortality rate need to take these cross-multiplication items into consideration. Taking Summer as an example, the effects of a 1% increase in average temperature on the mortality rate will be $\frac{\partial(\log \ \text{mortality})}{\partial(\log \ \text{temp})}$ =(-0.09)＋0.21＝0.12. This figure explains that the mortality rate increases by 0.12% if the average temperature increases by 1% in the Summer. Similarly, the effects of increasing the average temperature by 1% on the mortality rates in the Fall and Winter seasons are -0.05 and -0.21, respectively. In other words, mortality increases by 0.21% as the average temperature in winter decreases by 1%. These empirical results indicate that the effect of increasing the temperature by 1% on the mortality rate in Summer is smaller than the effect of decreasing the temperature by 1% on the mortality rate in Winter, which reflects the asymmetrical effects of changes in temperature on mortality rates in different seasons.

However, such effects of temperature with different seasons on the mortality rate may be affected by alternative locations. For instance, the estimation outcomes from Table 5 show that the effect of an increase in the average temperature of 1% in Summer in Europe on the mortality rate is 0.15 (i.e., $\frac{\partial(\log \ \text{mortality})}{\partial(\log \ \text{temp})}$＝ -0.28＋0.25＋0.18＝0.15), which is higher than that in non-European countries -0.03 (i.e., $\frac{\partial(\log \ \text{mortality})}{\partial(\log \ \text{temp})}$＝(-0.28)＋0.25＝-0.03). This empirical outcome indicates why heat waves occurring in Europe have resulted in more serious loss of human life than in other countries.

5. The Impacts of Climate Change on Mortality

The estimation outcomes of Models I to III in Tables 3 to 5 with their combinations of climate change scenarios from the IPCC [1, 61] may be used to derive the possible effects of climate change on mortality. The IPCC indicates that the global average temperature will increase by between 1.4 ℃ and 5.8 ℃, while the extent of the variation in temperature will be raised by between 4% and 17% in the year 2100 as compared with the year 2000. The future effects of climate change on temperature, precipitation, and temperature variation are shown in Table 6. On the other hand, the effects of climate factors on mortality rates through the estimation outcomes of Models I to III are summarized in Table 7. By integrating the empirical results and the extent of the future climate change scenarios, we can estimate the potential effects of climate change on mortality rates in OECD countries.

The potential impacts of temperature, precipitation and temperature variation induced by climate change on mortality rates are shown in Tables 8 and 9. The impacts of temperature due to climate change for different seasons in different locations could be found in Table 8. If seasons and locations are not taken into consideration, an increase in temperature will result in a decrease in mortality rates in OECD countries as shown in the column for Model I in Table 8. However, such negative effects of temperature on mortality rates will be positive in OECD countries in Summer. Furthermore, such effects will be more pronounced in the case of Europe.

Table 9 shows that both the effects of precipitation and temperature variation induced by climate change on mortality rates in OECD countries will be increased when the magnitudes of temperature variation are larger than those of precipitation. If the effects of temperature, precipitation, and temperature variation are summarized, the potential effects of climate change on mortality rates in OECD countries will be raised by between 3.77% and 5.89% by 2100 depending on seasonal and location factors as shown in Table 10 and Figure 2.

6. Conclusion

This study links climatic and macroeconomic factors together and applies a panel data model to estimate the effects of these two factors on the mortality rate in the capital cities of 22 OECD countries. Three major findings are derived. Firstly, countries with higher income and lower unemployment rates will have lower mortality rates while increases in precipitation and temperature variations will have significantly positive impacts on mortality rates. Secondly, the effects of increasing average temperatures on mortality rates depend on the seasons and country locations. These empirical results indicate that the effect of a 1% increase in temperature on the mortality rate in Summer is smaller than the effect of a 1% decrease in temperature on the mortality rate in Winter which exhibits an asymmetrical effect of changes in temperature on mortality rates for different seasons. However, such effects of temperature for different seasons on the mortality rate may be affected by alternative locations. The empirical results show that effect of a 1% increase in the average temperature in Summer in Europe on the mortality rate is five times greater than in non-European countries which indicates why heat waves occurring in Europe have resulted in more serious loss of human life than in other countries.

Finally, the potential effects of climate change on mortality rates in OECD countries are investigated. Mortality rates in OECD countries in 2100 will increase by between 3.77% and 5.89% depending on the seasons and country locations. Such figures imply that some possible adaptation strategies with respect to this damage on the part of the governments in OECD countries are provided and implemented. The warming system is the first issue to be addressed [62-63]. The research findings for the thresholds of heat waves and cold fronts on mortality rates could first be applied to a watch-warming system to prevent the occurrence of such damage. Later, building structures with air conditioning could stabilize the variations in such climate change. For instance, the air conditioning could reduce heat stroke by 400% [64]. Finally, an individual biophysical acclimatization with respect to climate variation may also play an important role in reducing mortality. All possible adaptation strategies by the government or the individual need to compare the costs of implementation with the potential benefits and then search for the best strategy to mitigate the potential damage caused by climate change in terms of higher rates of mortality.

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Table 1. Descriptive statistics of variables for 22 OECD countries

	Mean	Median	Maximum	Minimum	Std. Dev.
Mortality	2.006	2.032	4.057	0.988	0.454
GDP	2363.148	2202.037	7765.548	553.528	981.918
Unemployment	7.412	7.100	20.700	0.300	3.643
Temperature	52.793	52.520	86.180	9.140	14.272
Precipitation	68.438	54.050	1251.900	1.000	65.991
Variance of Temperature	9.998	8.389	47.844	0.558	6.492

Table 2. Panel LM unit root test with no break, one break, and two breaks

Variables	With no break	With one break	With two breaks
	Test statistic	Test statistic	Test statistic
Mortality rate	-1.712**	-2.097**	-9.414***
Real GDP per capita	1.363	-0.055	-7.901***
Unemployment rate	1.054	-0.318	-7.023***
Average temperature	-1.407*	-1.862**	-8.552***
Precipitation	-1.436*	-1.539*	-7.890***
Dew point temperature	-1.649**	-2.274**	-9.635***
Temperature variation	-1.571*	-1.933**	-9.157***

Notes: *, **, and *** respectively denote 1%, 5%, and 10% significance levels that reject the null hypothesis.

Table 3. Empirical results of Model I

Variables	Pooled OLS	FE model	RE model
	Parameter estimates		
Constant	2.35416**	2.11931**	2.11955**
	(0.08598)	(0.05920)	(0.07114)
Log prec	0.01506**	0.00249*	0.00247*
	(0.00282)	(0.00114)	(0.00114)
Log temp	-0.39435**	-0.20073**	-0.20116**
	(0.01848)	(0.00781)	(0.00781)
Log GDP	-0.77971**	-0.97937**	-0.97937**
	(0.07634)	(0.07015)	(0.06999)
Log unemployment	0.38852**	0.20258**	0.20417**
	(0.06079)	(0.03423)	(0.03421)
Log vartemp	0.46587**	0.27831**	0.27292**
	(0.05211)	(0.02107)	(0.02085)
Log dew	0.08151**	0.01926**	0.01856**
	(0.01736)	(0.00907)	(0.00707)
R^2	0.24202	0.89581	0.33191
Adj R^2	0.24111	0.89525	0.33111
F test		1489.86**	
LM test			3368.65**
Hausman Test			13.19*

Note 1: The numbers in parentheses are standard deviations.

2: * denotes statistical significance at the 5% level.

** denotes statistical significance at the 1% level.

Table 4. Empirical results of Model II

Variables	Pooled OLS	FE model	RE model
	Parameter estimates		
Constant	2.01634**	1.80187**	1.81065**
	(0.11132)	(0.06299)	(0.07048)
Log prec	0.01883**	0.00324*	0.00357*
	(0.00283)	(0.00154)	(0.00174)
Log temp	-0.10581**	-0.09172**	-0.08477**
	(0.02603)	(0.01033)	(0.01023)
Log GDP	-0.84285**	-0.99136**	-0.97128**
	(0.07661)	(0.06752)	(0.06729)
Log unemployment	0.38447**	0.21026**	0.21232**
	(0.00603)	(0.03291)	(0.03287)
Log vartemp	0.50175**	0.27132**	0.25126**
	(0.05185)	(0.02034)	(0.01982)
Log dew	0.09088**	0.01876**	0.01919**
	(0.01800)	(0.00715)	(0.00702)
Summer	0.13242**	0.19821**	0.19810**
	(0.01621)	(0.06457)	(0.06456)
Fall	-0.06888**	-0.04005**	-0.03262**
	(0.01466)	(0.01327)	(0.01327)
Winter	0.23369**	0.29569**	0.29738**
	(0.01012)	(0.03674)	(0.03674)
Summer*log temp	0.25176**	0.20719**	0.20760**
	(0.039821)	(0.01585)	(0.01585)
Fall*log temp	0.02423**	0.04136**	0.04171**
	(0.01041)	(0.01219)	(0.01819)
Winter*log temp	-0.20643**	-0.16793**	0.18291**
	(0.02654)	(0.07642)	(0.09642)
R^2	0.261478	0.90394	0.38325
Adj R^2	0.260706	0.90337	0.38177
F test		1585.98**	
LM test			3548.92**
Hausman Test			24.18*

Note 1: The numbers in parentheses are standard deviations.

2: * denotes statistical significance at the 5% level.

** denotes statistical significance at the 1% level.

Table 5. Empirical results of Model III

Variables	Pooled OLS	FE model	RE model
	Parameter estimates		
Constant	1.77625**	2.14159**	1.78177**
	(0.06702)	(0.06045)	(0.09659)
Log prec	0.00663**	0.00237*	0.00225*
	(0.00206)	(0.00117)	(0.00102)
Log temp	-0.41556**	-0.28292**	-0.28157**
	(0.01604)	(0.09029)	(0.08962)
Log GDP	-0.99145**	-0.97623**	-0.97673**
	(0.05503)	(0.06989)	(0.06864)
Log unemployment	-0.34212**	0.19958**	0.18918**
	(0.04524)	(0.00341)	(0.03307)
Log vartemp	0.32022**	0.30637**	0.31155**
	(0.03744)	(0.02102)	(0.02272)
Log dew	0.03894**	0.01078**	0.01110**
	(0.01381)	(0.00463)	(0.00424)
Summer	-0.85398**	-0.11226**	-0.10482**
	(0.10941)	(0.04230)	(0.04319)
Region	0.44653**		0.44012**
	(0.07929)		(0.08335)
Summer*log temp	0.36930**	0.24782**	0.24142**
	(0.02615)	(0.01492)	(0.01582)
Summer*Region*log temp	0.22004**	0.17661**	0.16966**
	(0.03059)	(0.01609)	(0.17991)
R^2	0.61702	0.89676	0.34086
Adj R^2	0.616254	0.89613	0.33954
F test		1200.93**	
LM test			3175.83**
Hausman Test			20.08*

Note 1: The numbers in parentheses are standard deviations.

2: * denotes statistical significance at the 5% level.

** denotes statistical significance at the 1% level.

Table 6. Percentage Change in Future Climate Change Scenarios

Year	Temperature	Precipitation	Temperature Variance
2020	0.56	1.100	0.72
2030	0.82	1.300	1.66
2040	1.14	1.700	2.97
2050	1.47	2.200	3.88
2060	1.82	2.600	6.81
2070	2.46	3.100	8.69
2080	3.29	3.500	11.38
2090	4.17	4.000	13.31
2100	5.80	5.600	17.61

Table 7. Percentage Change in Mortality Rates by Climate Factors

	Model I	Model II		Model III	
Temperature	-0.201	Spring	-0.091	Summer in non-Europe	-0.035
		Summer	0.115	Summer in Europe	0.142
		Fall	-0.050		
		Winter	-0.260	Not summer in 22 OECD countries	-0.283
Precipitation	0.002	0.003		0.002	
Temperature Variation	0.278	0.271		0.306	

Table 8. Impacts of temperature changes induced by climate change on mortality rates

Year	Model I	Model II				Model III		
		Spring	Summer	Fall	Winter	Summer in non Europe	Summer in Europe	Not summer in 22 OECD countries
2020	-0.11	-0.05	0.06	-0.03	-0.15	-0.02	0.08	-0.16
2030	-0.16	-0.08	0.09	-0.04	-0.21	-0.03	0.12	-0.23
2040	-0.23	-0.10	0.13	-0.06	-0.30	-0.04	0.16	-0.32
2050	-0.30	-0.13	0.17	-0.07	-0.38	-0.05	0.21	-0.42
2060	-0.37	-0.17	0.21	-0.09	-0.47	-0.06	0.26	-0.52
2070	-0.49	-0.20	0.25	-0.11	-0.56	-0.08	0.31	-0.61
2080	-0.66	-0.22	0.28	-0.12	-0.64	-0.09	0.35	-0.70
2090	-0.84	-0.25	0.31	-0.14	-0.71	-0.10	0.39	-0.77
2100	-1.17	-0.27	0.34	-0.15	-0.77	-0.10	0.42	-0.84

Table 9. Impacts of precipitation and temperature variation changes induced by climate change on mortality rates

Year	Mortality Rate Change due to Precipitation			Mortality Rate Change due to Temperature Variation		
	Model I	Model II	Model III	Model I	Model II	Model III
2020	0.003	0.004	0.003	0.20	0.19	0.22
2030	0.003	0.004	0.003	0.46	0.45	0.51
2040	0.004	0.006	0.004	0.83	0.80	0.92
2050	0.005	0.007	0.005	1.09	1.05	1.20
2060	0.006	0.008	0.006	1.91	1.84	2.11
2070	0.008	0.010	0.007	2.43	2.35	2.69
2080	0.009	0.012	0.009	3.19	3.07	3.53
2090	0.010	0.013	0.010	3.73	3.59	4.13
2100	0.014	0.018	0.013	4.93	4.75	5.46

Table 10. Impacts of climate change on mortality rates

Year	Model I	Model II				Model III		
		Spring	Summer	Fall	Winter	Summer in non Europe	Summer in Europe	Not summer in 22 OECD countries
2020	0.09	0.14	0.25	0.16	0.04	0.20	0.30	0.06
2030	0.30	0.37	0.54	0.41	0.24	0.48	0.63	0.28
2040	0.60	0.71	0.94	0.75	0.51	0.88	1.08	0.60
2050	0.80	0.93	1.23	0.99	0.68	1.16	1.42	0.79
2060	1.55	1.68	2.06	1.76	1.38	2.06	2.38	1.60
2070	1.95	2.16	2.61	2.25	1.80	2.62	3.01	2.09
2080	2.54	2.86	3.36	2.96	2.44	3.45	3.89	2.84
2090	2.90	3.35	3.91	3.46	2.89	4.04	4.53	3.37
2100	3.77	4.50	5.11	4.62	4.00	5.37	5.89	4.63

Appendix I. Descriptive statistics of monthly crude mortality rate in 22 OECD countries

Unit: ‰

	Mean	Median	Maximum	Minimum	Std. Dev.
Austria	2.13	2.09	2.80	1.76	0.22
Australia	1.51	1.46	2.66	1.18	0.22
Belgium	2.22	2.17	3.19	1.87	0.21
Canada	1.55	1.54	1.94	1.11	0.11
Switzerland	1.89	1.86	3.01	1.59	0.19
Germany	2.30	2.26	3.09	1.98	0.20
Denmark	2.44	2.41	3.69	1.99	0.26
Spain	1.92	1.86	2.90	1.58	0.22
Finland	2.08	2.04	2.85	1.83	0.16
France	1.99	1.96	2.70	1.71	0.18
Greece	2.06	2.04	3.20	1.65	0.20
Hungary	2.93	2.87	4.06	2.55	0.25
Italy	2.13	2.09	2.94	1.78	0.21
Japan	1.65	1.67	2.20	1.28	0.18
Korea	1.15	1.14	1.41	1.00	0.07
Netherlands	1.88	1.85	2.56	1.58	0.16
Norway	2.14	2.12	3.41	1.73	0.24
Poland	2.13	2.11	2.81	1.85	0.18
Portugal	2.23	2.13	3.79	1.79	0.34
Sweden	2.30	2.25	3.32	2.00	0.21
UK	2.30	2.23	3.68	1.71	0.32
USA	1.13	1.12	1.44	0.99	0.08

Appendix II. Descriptive statistics of monthly GDP per capita in 22 OECD countries

Unit: US dollars

	Mean	Median	Maximum	Minimum	Std. Dev.
Austria	3119.03	2457.24	4235.97	2038.90	528.79
Australia	3096.73	2376.14	3984.66	1878.21	507.76
Belgium	3037.07	2067.53	4161.39	1635.14	634.24
Canada	2626.74	2371.19	4131.69	2147.26	523.26
Switzerland	3698.20	3460.91	4012.52	3187.65	205.88
Germany	2621.29	2258.21	3945.86	1831.38	498.40
Denmark	3514.13	3048.13	3981.43	2510.46	295.63
Spain	1702.22	1700.85	2069.11	1390.40	216.69
Finland	3218.87	2174.95	4110.38	1704.20	567.98
France	2817.84	2217.37	3446.16	1772.09	382.28
Greece	1547.31	1462.95	2085.18	1178.19	253.06
Hungary	1014.73	963.157	1380.68	747.30	211.25
Italy	2238.37	2032.37	2261.57	1751.55	138.13
Japan	2154.35	2144.24	2425.22	1894.20	124.14
Korea	1391.21	1334.65	1994.49	842.04	324.69
Netherlands	3483.95	3163.89	3723.32	2516.40	364.48
Norway	4925.36	4634.12	7765.55	3806.26	906.95
Poland	838.48	834.73	1230.72	553.53	195.75
Portugal	1324.70	1379.62	1519.61	1075.34	138.66
Sweden	3497.59	2211.32	3897.59	1837.16	292.81
UK	2535.26	2524.24	3139.22	1985.82	328.64
USA	3007.11	3522.38	3957.33	2822.88	368.40

Appendix III. Descriptive statistics of monthly unemployment rate in 22 OECD countries

Unit: %

	Mean	Median	Maximum	Minimum	Std. Dev.
Austria	6.53	6.25	9.30	4.30	1.26
Australia	7.11	6.85	10.90	3.90	1.93
Belgium	8.09	8.10	9.90	6.30	1.11
Canada	8.28	7.80	12.10	5.80	1.69
Switzerland	3.16	3.31	5.70	0.43	1.31
Germany	10.59	10.80	14.10	6.10	1.76
Denmark	7.14	6.00	14.60	1.60	3.19
Spain	13.19	12.70	19.80	8.00	3.51
Finland	10.20	9.20	17.60	2.90	3.60
France	9.67	9.30	11.80	7.60	1.24
Greece	9.00	8.90	12.40	6.20	1.62
Hungary	8.48	7.70	13.60	5.60	2.35
Italy	9.17	8.90	11.40	5.90	1.63
Japan	3.78	4.00	5.50	2.00	1.07
Korea	3.46	3.20	8.80	1.80	1.40
Netherlands	4.40	4.25	8.00	1.70	1.78
Norway	3.60	3.60	6.30	1.50	1.19
Poland	14.00	14.40	20.70	0.30	4.20
Portugal	5.98	6.35	8.30	3.80	1.46
Sweden	6.60	6.40	10.50	1.40	2.20
UK	5.16	4.15	9.90	2.40	2.52
USA	5.46	5.40	7.80	3.80	0.96

Appendix IV. Descriptive statistics of monthly average temperature in 22 capital cities of OECD countries

Unit: ˚F

	Mean	Median	Maximum	Minimum	Std. Dev.
Austria	52.06	52.16	77.18	26.78	13.48
Australia	56.18	55.49	74.30	40.64	9.44
Belgium	52.11	51.44	73.76	31.64	10.01
Canada	46.91	47.21	75.74	9.68	17.71
Switzerland	50.25	49.82	73.94	28.58	12.08
Germany	49.52	48.29	71.78	26.78	11.06
Denmark	44.51	43.88	55.22	35.06	5.23
Spain	60.44	59.65	82.58	37.04	12.65
Finland	41.91	41.72	68.90	9.14	14.56
France	52.19	51.44	75.74	27.32	11.97
Greece	65.18	62.60	86.18	44.96	11.91
Hungary	52.71	53.51	78.44	24.98	14.63
Italy	62.40	63.59	85.46	41.36	13.42
Japan	58.02	58.60	83.12	44.6	11.18
Korea	56.06	57.92	84.20	24.98	17.27
Netherlands	51.33	50.18	78.26	30.02	9.97
Norway	41.77	40.91	67.28	10.04	13.88
Poland	47.80	48.02	73.58	17.06	13.83
Portugal	63.08	62.15	78.08	48.56	7.91
Sweden	43.79	42.98	67.46	15.80	12.73
UK	50.78	49.82	77.54	34.70	8.44
USA	58.48	58.28	83.12	28.76	15.23

Appendix V. Descriptive statistics of monthly temperature variation in 22 capital cities of OECD countries

	Mean	Median	Maximum	Minimum	Std. Dev.
Austria	11.67	9.95	37.88	3.10	6.48
Australia	8.56	7.56	24.13	1.67	4.10
Belgium	10.15	8.71	28.69	2.27	5.62
Canada	12.36	9.83	36.07	2.23	8.11
Switzerland	10.73	9.82	30.36	2.93	5.51
Germany	13.03	12.02	39.97	3.11	6.64
Denmark	5.95	5.32	20.48	1.03	3.44
Spain	7.85	6.76	30.19	1.68	4.27
Finland	12.52	10.57	34.74	0.64	7.59
France	10.03	9.32	27.32	2.16	5.07
Greece	6.23	5.45	19.53	0.56	3.92
Hungary	12.06	10.26	39.42	2.32	6.97
Italy	6.16	5.47	23.80	0.68	3.79
Japan	7.10	6.64	23.68	1.19	3.41
Korea	10.93	9.37	37.34	1.62	6.47
Netherlands	9.51	8.41	28.83	1.53	5.55
Norway	12.20	10.05	36.14	1.44	8.21
Poland	13.00	11.05	35. 40	2.35	7.47
Portugal	5.55	4.50	23.59	0.92	3.61
Sweden	11.07	9.55	37.18	1.53	6.60
UK	8.33	7.67	31.22	1.28	4.05
USA	14.81	12.95	43.53	1.95	8.54

Appendix V. Descriptive statistics of monthly average precipitation in 22 capital cities of OECD countries

Unit: mm

	Mean	Median	Maximum	Minimum	Std. Dev.
Austria	54.04	48.25	231.60	1.90	35.37
Australia	48.84	39.31	218.00	1.00	37.94
Belgium	68.29	63.25	231.00	0.10	38.60
Canada	64.49	61.80	193.20	1.00	34.95
Switzerland	95.32	85.98	287.00	6.00	54.30
Germany	66.53	57.55	212.50	0.10	39.48
Denmark	116.89	106.01	307.00	5.00	56.80
Spain	26.83	17.65	168.30	0.20	28.42
Finland	56.43	51.00	216.00	3.00	37.11
France	53.44	50.42	134.00	5.00	29.45
Greece	49.73	22.10	421.20	0.10	66.02
Hungary	43.97	37.90	170.40	0.01	32.32
Italy	37.29	24.00	213.00	0.01	41.08
Japan	130.29	114.75	785.50	0.50	98.15
Korea	126.17	60.50	1250.90	0.10	179.65
Netherlands	71.25	67.50	211.00	4.00	39.27
Norway	70.94	66.00	299.00	1.00	40.95
Poland	43.83	37.60	220.60	1.00	29.72
Portugal	56.30	37.15	353.00	0.01	63.23
Sweden	57.01	53.00	176.00	3.00	32.73
UK	69.66	68.00	220.00	7.00	36.86
USA	84.91	80.50	357.70	0.90	49.81