An Integrated Assessment of Climate Change-Driven Temperature Impacts on Health and Labor Force Participation in Taiwan

Ching-Cheng Chang[1,2], Chia-Sheng Hsu[1], Shih-Hsun Hsu[2]

[1]Institute of Economics, Academia Sinica, Taiwan

[2]Department of Agricultural Economics, National Taiwan University, Taiwan

Abstract

Climate change can have a range of negative effects on human health. People with pre-existing medical conditions such as cardiovascular disease, people carrying out physically demanding work and the elderly are particularly vulnerable. Moreover, Taiwan has officially entered the stage of an "aged society" as Taiwanese people over 65 years old accounted for 14.05% of the country's total population in 2018. Cardiovascular disease (CVD) is one of the main causes of morbidity and mortality among the elderly in Taiwan. Therefore, this study aims to study the cardiac health consequences of climate change with focuses on the increasing heat exposure and the economic implications to Taiwan's labor market. The analysis is divided into two stage. First, a county-level panel data set from 1998 to 2015 is used to estimate the health damage function from CVD. Second, climate data from statistical downscaling of GCM projections and demographic data projected by GEMTEE (General Equilibrium Model for Taiwanese Economy and Environment) up to year 2050 are integrated into the estimated health damage function as new inputs to GEMTEE to simulate future mortality and health expenditures due to CVD under different climate scenarios. On the health side, the results indicate that a 1℃ increase in average summer temperature, average winter temperature, and spatial variation are associated with 2.9%, 1.3% and 14.3% increases in the numbers of CVD deaths respectively. There will be additional 4,200-4,500 CVD deaths (including 900-1,000 deaths of labor force) per year from 2021 to 2040. This number rises to about 5,600-6,300 CVD deaths and additional 600-800 losses of labor force per year from 2041 to 2060. The findings also show that climate change will lead to increases in both mortality and morbidity of CVD. So on the expenditure side, a 1% increase in average summer and winter temperature could lead to 1.37% and 0.47% increases in CVD-related health expenditure respectively. However, a 1% increase in annual precipitation causes a 0.08% decrease in CVD-related health expenditure. The simulated results of GEMTEE indicates that the health impacts due to both climate change and aging population will lead to a 0.58% decline in real GDP per year in the short term (2020-2030), while in the long term (2030-2060) real GDP decreases by 1.77% to 1.96% per year. The significant economic cost of both deaths and health expenditures due to climate change cannot be ignored especially for a rapidly aging society like Taiwan and policy options to foster resilience should be in place to address this emerging issue.

Keywords: Climate Change, CVD, Labor force, Aged society, Integrated Assessment

1. Introduction

According to the Fifth Assessment Report (AR5), by the Intergovernmental Panel on Climate Change (IPCC), future global warming will force human beings to face increasing risk of heat-related disease and death, which may have negative impacts on the labor force, economy and society. CVD in this study includes heart disease, cerebrovascular disease and hypertensive disease, which are not only among the top two causes of death in Taiwan, but also an important issue in Taiwan's public health research. These diseases caused 32,658 deaths in 2016, on average 84 deaths every day (MOHW, 2017). Additionally, the historical temperature data of Taipei's main meteorological station show that the average annual temperature rose from 21.8℃ to 23.4℃ in the past hundred years (1897-2013); this increase is over twice the global average temperature increase. The annual days of extremely high temperature rose from 1 day to 24 days; the annual days of extremely low temperature declined from 14 days to 2 days during the period from 1987 to 2013 (TCCIP, 2017).

That is, we can see from the changing pattern of historical data that Taiwan faces high risk of climate change, and such changes will have serious consequences for the population's health in different ways. Most existing studies investigated the relationship between temperature and mortality with a focus on the city level, and some studies have projected mortality under different climate scenarios (Cheng *et al.*, 2009; Li *et al.*, 2015). However, only a few studies have considered the effects of demographic change on mortality (Dessai, 2003; Jackson *et al.*, 2010, Li *et al.*, 2016). The mortality or morbidity due to climate change directly impacts health expenditure, labor supply and labor productivity, thus indirectly affecting the key factors of macro-economic development, such as household consumption, industrial production, labor wage, etc. Therefore, investigating the effects of climate change on mortality and morbidity is meaningful for further discussion of the strategy of economic growth under the challenge of climate change.

Furthermore, Taiwan will face the problem of an aging population in the near future, and CVD is a higher risk for the elderly population. Hence, we can expect that climate change will increase the risk of CVD and further lead to increases in health expenditure due to CVD in the future. The social cost of both death risk and increased health expenditure caused by climate change under an aged society should be discussed. Therefore, to project the future CVD deaths and CVD-related health expenditure due to climate change under the aging demographic structure. Econometric methods of panel count data estimation and panel data model are employed, and both population forecast by the General Equilibrium Model for Taiwanese Economy and Environment (GEMTEE) (Lin *et al.*, 2015) and climate data projected by Taiwan Climate Change Projection and Information Platform (TCCIP) are used to arrive at our results.

2. Materials and Methods

2.1. Health damage model

We will establish a health damage model with explanatory variables including climate factors, an index of air pollution, and real household income to estimate the effects of the aforementioned factors on CVD mortality. This study employs a panel count data model to build a health damage model of CVD, and we represent it as follows:

$$P\left(y_{it}\middle|\mu_i,x_{it}\right)=\frac{\exp(-\lambda_{it})\,\lambda_{it}^{y_{it}}}{y_{it}!} \quad (1)$$

$$E\left[y_{it}\middle|x_{it}\right]=\lambda_{it}=\mu_i\exp\left(x_{it}^{'}\beta\right) \quad (2)$$

$$P\left(y_{it}\middle|\delta_i,x_{it}\right)=\frac{\Gamma\left(\lambda_{it}+y_{it}\right)}{\Gamma\left(y_i+1\right)\Gamma(\lambda_{it})}\left(\frac{1}{1+\delta_i}\right)^{\lambda_{it}}\left(\frac{\delta_i}{1+\delta_i}\right)^{y_{it}} \quad (3)$$

$$E\left[y_{it}\middle|x_{it}\right]=\lambda_{it}=\exp\left(x_{it}^{'}\beta+\mu_i\right) \quad (4)$$

$$x_{it}^{'}\beta:\ \beta_0+\beta_1 Summer_{it}+\beta_2 Winter_{it}+\beta_3 SD_{it}+\beta_4 Rain_{it} +\beta_5 PSI_{it}+\beta_6 Income_{it}+\beta_7 Income_{it}^2+\varepsilon_{it} \quad (5)$$

Equation (1) and equation (2) show the probability mass function and conditional expected value of a panel Poisson model, respectively. Equation (3) and equation (4) are the probability mass function and conditional expected value of panel NB models, respectively. μ_i is the term of individual effect; λ_{it} means the conditional expected value of the Poisson distribution; y_{it} is the annual number of CVD deaths; δ_i is the parameter of dispersion for each individual; in particular, a random effect over-dispersion model allows δ_i to randomly vary across individuals, and $1/(1+\delta_i)$ follows the distribution of Be(r,s). $x_{it}^{'}$ stands for explanatory variables, including the average temperature in summer ($Summer_{it}$), the average temperature in winter, the annual variation of temperature (SD_{it}), and the annual average of rainfall ($Rain_{it}$). PSI_{it} means the percentage of cumulative days in a year that the pollutant standards index (PSI) is larger than 100, and $Income_{it}$ is real household disposable income. The coefficient (β) is semi-elasticity, meaning the percentage changes of response variables caused by a unit change in an explanatory variable.

2.2. Health expenditure model

We also establish a health expenditure model of CVD to analyze the impacts of each explanatory variable on CVD-related health expenditure, and the panel data model is employed here. Marino *et al.* (2017) proposed that a cross-country model of macro health expenditure should incorporate income, technological advancement, changes in labor productivity, and demographic structure. we express the health expenditure model of CVD with equation (6).

$$\ln Expenditure_{it}=\theta_i+\alpha_0+\alpha_1\ln Summer_{it}+\alpha_2\ln Winter_{it} +\alpha_3\ln SD_{it}+\alpha_4\ln Rain_{it}+\alpha_5 PSI_{it}+\alpha_6\ln Income_{it}+\alpha_7\ln Elder_{it} +\alpha_8\ln Child_{it}+\alpha_9\ln Labor_{it}+\varepsilon_{it} \quad (6)$$

The definition of explanatory variables in equation (6) is the same as the previous health damage model of CVD, except $Expenditure_{it}$, $Elderly_{it}$, $Children_{it}$, and $Adult_{it}$. In equation (6), $Expenditure_{it}$ means the total amount of CVD health expenditure at time t in city or county i, and $Elderly_{it}$, $Children_{it}$, and $Adult_{it}$ respectively mean those 65 years old and above, under 14 years old, and between 15 and 64 years old. In addition, we take the natural logarithm of all variables except PSI_{it} in equation (6), and it should be noted that we don't convert PSI_{it} into natural logarithm because the unit of PSI_{it} is percentage. Therefore, all coefficients (α_1 to α_9) in equation (6) can be interpreted with elasticity, meaning a percentage change in the explanatory variable causes the percentage changes in response variables.

2.3. Data description and process

There is a lower density of observation stations in mountainous regions than flat regions, and a significant difference in climate between alpine regions and flat regions in Taiwan, and the flat regions have more human activity in daily life, so this study first uses the condition of below 800 meters above sea level for selecting observation stations, and subsequently classifies the observation stations according to the city they belong to. Thus, we retain 642 observation stations from among the 770 observation stations, and use the observed data of the 642 observation stations to compute the climate data used in this study. After the data processing, we report the statistical description for each variable in Table 2.

Table 2. The statistical description

Variable	Unit	Maximum	Minimum	Mean	S.D.
Total deaths of CVD	Person	4,470	109	1,399.322	987.840
CVD deaths of adults	Person	1,193	13	313.301	243.916
CVD deaths of elderly	Person	3,269	88	1,083.5	749.356

CVD deaths of children	Person	14	0	2.520	2.720
Total amount of CVD health expenditure	1000 RVU	6,993,243	156,906	137,932	1,508,931
Average temperature in summer	℃	29.243	24.691	27.349	1.004
Average temperature in winter	℃	21.445	13.762	17.047	1.443
Annual variation of temperature	℃	1.751	0.004	0.933	0.460
monthly average of rainfall	mm	193.23	19.23	65.27	33.53
PSI>100	%	22.340	0	2.453	2.902
Household disposable income	TWD	1,314,031	504,624	819,149.1	151,706.3
Population of adults	Person	3,035,481	59,760	849,584.3	781,700.1
Population of elderly	Person	429,175	12,205	119,139.7	95,088.3
Population of children	Person	964,747	15,104	257,576.3	234,730.0

3. Empirical Results

According to estimated results of health damage model, we find out that the average temperature in summer has a significant, positive impact on mortality of CVD for all age groups at the significance level of 1%, such that a 1℃ increase in the average temperature in summer causes a 2.9% increase in the risk of CVD mortality. The average temperature in winter has a significant, negative impact on mortality of CVD for all age groups at the significance level of 5%, and the estimated coefficient indicates that a 1℃ decrease in the average temperature in winter causes a 1.3% increase in the risk of CVD mortality.

We also find that the variation of temperature has a significant, positive impact on mortality of CVD, such that a 1℃ increase in the variation of temperature causes a 14.3% increase in the risk of CVD mortality. There is thus higher death risk due to CVD due to the variation of temperature than due to the average temperature in summer and winter. Moving to the results of health expenditure model, both the average temperature in summer and winter have statistically significant impacts on CVD-related health expenditure at the 5% significance level, such that a 1% increase in average temperature in summer causes a 1.371% increase in total health expenditure due to CVD; a 1% decrease in average temperature in summer causes a 0.469% increase in total health expenditure due to CVD, which also implies that both higher and lower temperature lead to higher hospital admissions, resulting in higher health expenditure. Hence, we combine the estimated results with TCCIP's climate grid data of 5 km scale, which are the statistically downscaled output of Global Climate Model (GCM) projections. TCCIP's projection of climate data is supported by Taiwan's Ministry of Science and Technology, and has high reliability due to both the physical basis of the climate model and the data science methods used.

Therefore, we can employ the significant coefficients of climate factors in the estimation of health damage to compute the possibly additional future impact of climate factors ($\mathrm{Summer_{it}}$, $\mathrm{Winter_{it}}$, $\mathrm{SD_{it}}$) on the risk of CVD mortality for different groups in each city in Taiwan. Figure 1 and Figure 2 respectively shows the computed result of future CVD deaths of labor force and elderly caused by climate change under demographic change. On average, the computed results indicate that there will be additional 4,200-4,500 CVD deaths per year over the period from 2021 to 2040; this rises to about 5,600-6,300 CVD deaths per year over the period from 2041 to 2060 when both climate change and aging of the population are considered as causes.

That is, climate change will lead to more deaths from CVD in the near and medium-range future in Taiwan. Moreover, the rapidly aging population will exacerbate the CVD health risks.

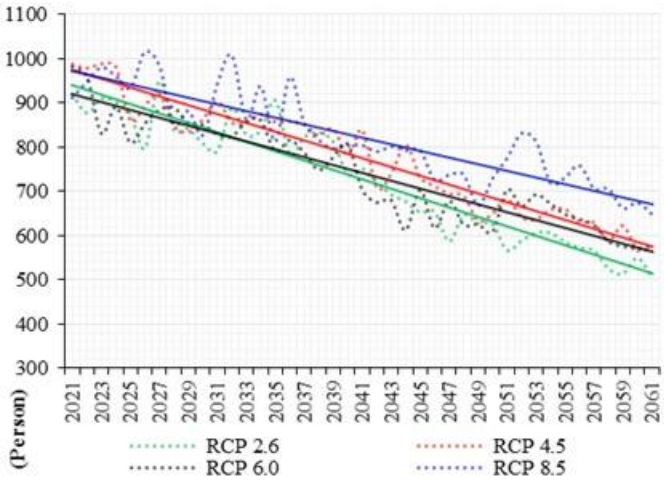

Figure 1. The average CVD deaths of labor force under different climatic scenarios

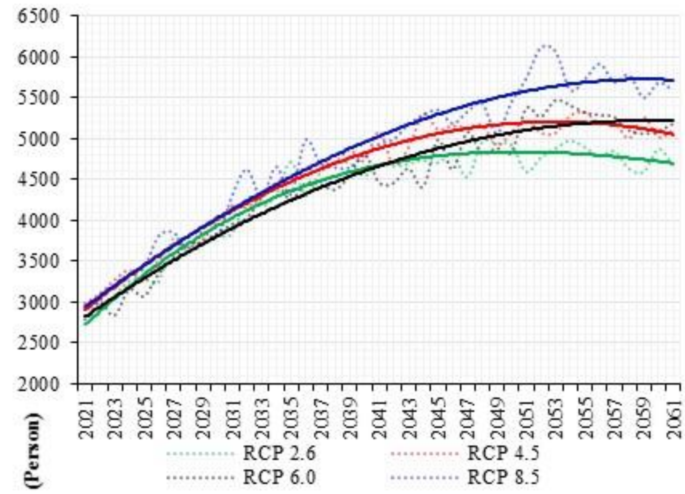

Figure 2. The average CVD deaths of elderly under different climatic scenarios

On the other hand, Taiwan's total amount of CVD health expenditure (see Figure 3) caused by climate change and population aging will be 12.592 hundred million TWD under RCP2.6 and 12.594 hundred million TWD under RCP8.5 per year over the period from 2021 to 2040. Also, Taiwan's total CVD health expenditure caused by climate change and population aging will be 13.110 hundred million TWD per year under RCP2.6 and 13.154 hundred million TWD per year under RCP8.5 over the period from 2041 to 2060. That is, if international efforts can't efficiently reduce GHG emissions, there will be higher social cost of Taiwan's CVD health expenditure in the near future. Finally, GEMTEE is integrated into health damage and health expenditure to simulate the total economic impactions of climate change on CVD health. Table 3 reports GEMTEE's simulation of labor force losses caused by climate change.

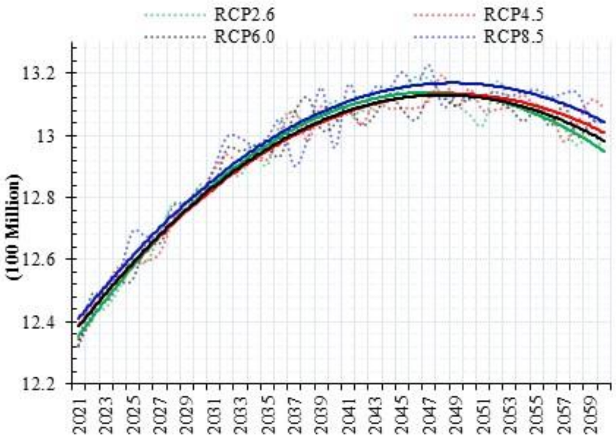

Figure 3. The additional health expenditure of CVD under different climatic scenarios

Table 3. The labor force lost for each sector caused by health impactions due to climate change

Sector		Time period					
		(2020-2030)		(2031-2045)		(2046-2060)	
		Person	%	Person	%	Person	%
RCP 2.6	Agriculture	-9,826	-1.76	-13,675	-3.64	-9,403	-4.66
	Industrial	-57,245	-2.13	-78,223	-4.81	-43,853	-6.11
	Service	-104,304	-1.63	-136,322	-2.99	-103,066	-3.76
RCP 4.5	Agriculture	-9,823	-1.76	-13,629	-3.62	-7,480	-3.38
	Industrial	-57,414	-2.13	-77,437	-4.75	-33,378	-3.88
	Service	-104,212	-1.63	-136,791	-3.01	-107,589	-3.99
RCP 6.0	Agriculture	-9,823	-1.76	-13,878	-3.71	-8,984	-4.44
	Industrial	-57,408	-2.13	-80,966	-5.06	-37,577	-5.14
	Service	-104,206	-1.63	-134,600	-2.95	-107,337	-3.92
RCP 8.5	Agriculture	-9,824	-1.76	-13,627	-3.62	-10,088	-5.14
	Industrial	-57,417	-2.13	-77,409	-4.75	-48,752	-7.22
	Service	-104,216	-1.63	-136,818	-3.01	-100,349	-3.64

The simulated results of GEMTEE indicates that the health impacts due to both climate change and aging population will lead to a 0.58% decline in real GDP per year in the short term (2020-2030), while in the long term (2030-2060) real GDP decreases by 1.77% to 1.96% per year. The significant economic cost of both deaths and health expenditures due to climate change in Taiwan cannot be ignored, especially for a rapidly aging society like Taiwan.

4. Conclusions

In summary, we respectively investigate the long-run impacts of climate change on deaths from CVD and CVD-related health expenditure. We find that global warming will lead to increased mortality and morbidity of CVD in summer and decreases in winter. In general, climate change will cause higher health risk from CVD and different degrees of impact in different areas. The effects of climate change on CVD risk not only will result in rising health expenditure but also will lead to negative economic impacts due to increasing CVD deaths among those aged 15 to 64 under higher heat exposure. However, we don't quantify the economic effects of climate change on CVD deaths for adult group in this study, but we infer that the decline in the labor force due to both climate change and an aging population structure will exacerbate the negative impacts on the economy in the future in Taiwan.

For the simulated results, we should note the aging problem and the different death risk for different areas. In addition to the six municipalities, there is also high death risk in rural counties, such as Yilan, Taitung, Pingtung, Keelung and Hualien counties, and there will be high ratio of elderly to adults in those counties in the near future; that is, if policy makers want to implement measures of health adaptation to reduce the public health risk from CVD under climate change, such as building early warning systems, establishment of local cooling centers, increasing access to quality water, and air conditioning (Deschenes, 2014), they could give priority to areas which are poorer, have higher risk of CVD, and have more rapidly aging populations.

On the other hand, mitigation of GHGs can provide not only direct positive environmental effects, but also external benefits which are defined as co-benefits (Smith *et al.*, 2014). For instance, if low-emission vehicles, electric vehicles, green public transport, etc. are promoted as policy instruments to reduce GHG emissions, they can reduce not only carbon emissions, but also air pollution, traffic congestion, noise and another issues (Yang *et al.*, 2016). Additionally, they can also improve environmental ecology and health problems, and reduce the overall social potential costs (Rashidi *et al.*, 2017). In this study, both death risk and CVD-related health expenditure are affected by both climate change and demographic change, and this will increase with higher GHG emissions and as time passes.

Therefore, we suggest that public health measures such as individual and community-level health monitoring and prevention systems should be strengthened as adaptations to reduce CVD-related death risk in the short run. In the long-run, integrated assessments on negative health impacts of climate change on the aging labor force should be mainstreamed into the macro-economic policy. Public information campaigns and financial support for undertaking adaptive measures should also be promoted as long-term adaptation strategies..

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