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Margins of Adaptation to Human Heat Stress: Local, National, and Global Socioeconomic Responses

By IMAN HAQIQI*, JONATHAN BUZAN, CICERO DE LIMA, THOMAS W HERTEL

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The majority of agricultural climate impact studies focus on crop yields, ignoring the impacts on labor productivity. The few studies on global labor productivity impacts of climate tend to ignore socioeconomic adaptations. This study provides a multi-scale and multi-sector analysis of how the socioeconomic system responds to lower labor capacity due to climate-induced heat stress. Combining the GTAP (Global Trade Analysis Project) framework with high-resolution projections of climate and population, we quantify the cascading economic impacts of heat stress as it alters labor capacity in both the agricultural and non-agricultural sectors. Then we investigate the role of different adaptation solutions at local, regional, and global scales. This includes investing in automation, changing production location, labor migration, domestic and international trade, and changes in patterns of consumption as well as in the changes in the structure of national economies. (JEL: C68, J24, Q54, R13)

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* Iman Haqiqi, Department of Agricultural Economics, Purdue University, 403 West State Street West Lafayette, Indiana 47907-2056 USA (email: ihaqiqi@purdue.edu).

1 Introduction

Heatwaves are a danger to public health. Their impact on mortality, health, and productivity has been studied around the world including Europe (Kovats and Kristie, 2006; Murage et al., 2017), the United States (Knowlton et al., 2009; Anderson and Bell, 2011), Australia (Hansen Alana et al., 2008) and China (Bai et al., 2016). The fact that "*heatwaves have increased in intensity, frequency, and duration*" (Perkins-Kirkpatrick and Lewis, 2020) raises significant concerns about the likely impacts on human health and people's capacity to work outdoors in the future (Buzan and Huber, 2020). Also, it suggests the potential for widespread indirect impact on food production, food prices, economic activities, and labor income which affects people's life and welfare (Hertel and de Lima, 2020).

In this study, we focus on the impact of climate change on labor capacity. While the majority of climate impact studies in agriculture focus on crop yields, there is a growing literature quantifying the impact of heat stress on labor capacity (Kjellstrom et al., 2009; Willett and Sherwood, 2012; Dunne et al., 2013; Zander et al., 2015; J. R. Buzan and Huber, 2020). While few studies discussed the economic costs of human heat stress (Dunne et al., 2013; Knittel et al., 2020; Orlov et al., 2020), emerging studies on labor productivity impacts tend to ignore socioeconomic adaptations. Adaptation options can reduce the damages from climate change and heat stress. However, the significance of adaptation channels is yet to be quantified.

This study makes a couple of significant contributions. In addition to providing a global database of estimated labor productivity impacts, our contribution is to measure the benefits of each adaptation margin in a multi-scale and multi-sector framework. Combining the GTAP (Global Trade Analysis Project) framework with high-resolution projections of climate and population, we quantify the economic value of global damage of heat stress through lower labor capacity in the agricultural and non-agricultural sectors. We investigate the role of adaptation solutions at local, regional, and global scales. This includes capital-labor substitution to automate physically demanding activities, changing production location, domestic and international trade, and changes in patterns of consumption as well as national economies' sectoral structure. The methods can be used in a wide range of studies to evaluate climate change considering other health impacts.

2 Methods

We extend Lima et al. (2019) with updated estimates of climate impacts on agricultural labor. We also consider a unique fine-scale estimate of the climate impacts on non-agricultural labor consistent with GTAP, ILO (International Labour Organization), and BLS (the United States Bureau of Labor Statistics) categories.

2.1 Gridded climate impact on labor capacity

We take the shocks from labor capacity losses. The labor capacity is derived from heat stress calculations NIOSH labor capacity algorithms (Bröde et al., 2018), using the Environmental Stress Index (Moran et al., 2001) and Simplified Wet Bulb Globe Temperature (Willett and Sherwood, 2012) as approximations for the Wet Bulb Globe Temperature (WBGT), an international standard for workplace heat stress (Parsons, 2006). The environmental data for ESI and sWBGT are calculated from CMIP5 climate projections (Taylor et al., 2012). Note that solar radiation is included in the ESI metric, whereas sWBGT assumes maximum solar exposure. Based on the ensuing ensemble distribution of estimated heat stress impacts, we choose the high, medium, and low estimates of labor capacity loss due to heat stress. The shocks are calculated considering 6 hourly temperature and humidity. Then we take the average productivity around the year 2010 and the year 2050. The shocks are calculated at 30 arc-min grid cells. Then we aggregate the gridded shocks to the national level using crop area weights. For the non-agricultural sectors, we use gridded population weights to aggregate shocks (CIESIN, 2018).

2.2 Regional impact on labor productivity by economic sector and labor type

Here, we introduce a new method to translate the potential labor capacity loss to productivity loss by labor types and different economic sectors. We distinguish between labor type and occupation. Labor type refers to the labor categories in GTAP. Occupation refers to the occupations within each labor type. Table 1 show the relationship between occupation and labor types. Note that the heat stress on each occupation varies by the associated economic sector. We construct a strength requirement dataset by occupation, economic sector, and the share of four strength requirement tasks (light work, medium work, heavy work, very heavy work). We also construct a dataset of exposure to outdoor and heat stress specific to each occupation and economic sector based on BLS.

Table 1: Occupations in each GTAP labor category

GTAP labor types	Collar	Occupations
Officials and Managers	White	Management Occupations
		Business and Financial Operations Occupations
Technicians and Professional	Purple	Computer and Mathematical Occupations
		Architecture and Engineering Occupations
		Life, Physical, and Social Science Occupations
		Community and Social Service Occupations
		Legal Occupations
		Education, Training, and Library Occupations
		Arts, Design, Entertainment, Sports, and Media Occupations
Service/Shop workers	Pink	Healthcare Practitioners and Technical Occupations
		Healthcare Support Occupations
		Protective Service Occupations
		Food Preparation and Serving Related Occupations
		Building and Grounds Cleaning and Maintenance Occupations
		Personal Care and Service Occupations
		Sales and Related Occupations
Clerks	White	Office and Administrative Support Occupations
Agricultural and Unskilled	Blue	Farming, Fishing, and Forestry Occupations
		Construction and Extraction Occupations
		Installation, Maintenance, and Repair Occupations
		Production Occupations
		Transportation and Material Moving Occupations

Considering detailed labor-occupation-activity information, we calculate the impacts on labor productivity for each economic activity (a) and labor type (i) in each region (r). The shock on each labor type depends on the required strength or working rate (i). The shock to each labor type is calculated by considering the share of each level of strength required (α) and the amount of exposure to outdoor (β) specific to each occupation. For each warming scenario (sc) we calculate the productivity shock as:

$$z_{l,a,r}^{sc} = \beta_{l,a}\left(\sum_i \alpha_{l,a}^{i} z_r^{i,sc}\right), \; i\text{=200W, 300W, 400W, 600W, sc=1C-5C warming} \qquad (1)$$

where, $z_r^{i,sc}$ is the projected potential shock on labor capacity in region r for each working rate (i). Here, β considers different durations of outdoor exposure for each occupation according to the following equation.

$$\beta_{l,a} = \sum_k \theta_{k,l,a} \omega^d \text{ , d= constantly, frequently, occasionally, seldom, no exposure.} \qquad (2)$$

where, $\theta_{k,l,a}$ is the share of each outdoor exposure type by occupation by labor type and economic activity. We assume the various values for ω depending on outdoor exposure. The share of each strength level by labor type is a weighted average if this indicator from occupations. The regional shocks are calculated from grid cell level projections. We aggregate the grid-cell level shocks to the national level using the gridded population for non-agriculture and the gridded value of production for agriculture as follows:

$$\begin{aligned} z_r^{i,sc} &= \sum_{grid \in r} \frac{pop_{r,grid}}{pop_r} z_{r,grid}^{i,sc} \\ z_r^{i,sc} &= \sum_{grid \in r} \frac{val_{r,grid}}{val_r} z_{r,grid}^{i,sc} \end{aligned} \text{, } i\text{=200W, 300W, 400W, 600W, } sc\text{=1C-5C warming} \qquad (3)$$

2.3 Model

The main modeling framework is the GTAP model (Corong et al., 2017), based on v10 Data Base with 141 regions (Aguiar et al., 2019). Using the estimated shocks, we evaluate the impacts of climate change and compare the outcomes of different model closures illustrating adaptation possibilities. This includes no adaptation, capital investment, international trade, labor migration and movements, as well as changes in diets and consumption patterns.

The labor market clears assuming labor mobility across sectors without skill upgrading. There is another labor shift in the model assuming labor migration within a region across different grid cells in response to climate shocks. We assume no migration across regions.

3 Results

This study provides a comprehensive database for the estimated impacts of climate change on labor capacity by economic sector, labor type, region, and global warming scenarios. Figure 1 illustrates our calculations on the impacts of climate change on labor capacity compared to the 1986-2005 period for 400W for ESI (Environmental Stress Index) for different scenarios of global warming according to the median of 18 CMIP5 climate models. The labor in India, Sub-Saharan Africa, Indonesia, and South America is highly affected by climate-induced heat stress. However, the shock on each labor category and each economic sector is determined with equations 1-3. For example in the 5C-ESI scenario in South East Asia, the productivity of low-skilled labor in the construction sector is expected to decline by 17.1% while the labor capacity for professionals and managers is expected to decline only by 0.28%. Considering different scenarios of climate impacts, we quantify the impacts of climate-induced labor capacity loss on the economic well-being of regions around the world.

Technically, this study provides a novel approach to quantify the impacts of climate change on human well-being by integrating knowledge and data from various disciplines. While climate models provide estimates of future heat stress, the health sciences provide the framework to quantify the impacts of projected heat on labor capacity at each location. Finally, the GTAP model can connect economic activities around the world through the international trade of commodities and measure the ensuing adaptations.

The results of this study can help policymakers by showing the relative significance of different adaptation strategies. This can lead to a more efficient allocation of research funding to the most significant adaptation possibilities. It also helps the governments to have a better understanding of the likely benefits of adaptive investments in the health system. Finally, it can assist international humanitarian organizations in identifying the potential hotspots and thinking about adaptive solutions to reduce the negative impacts of climate change.

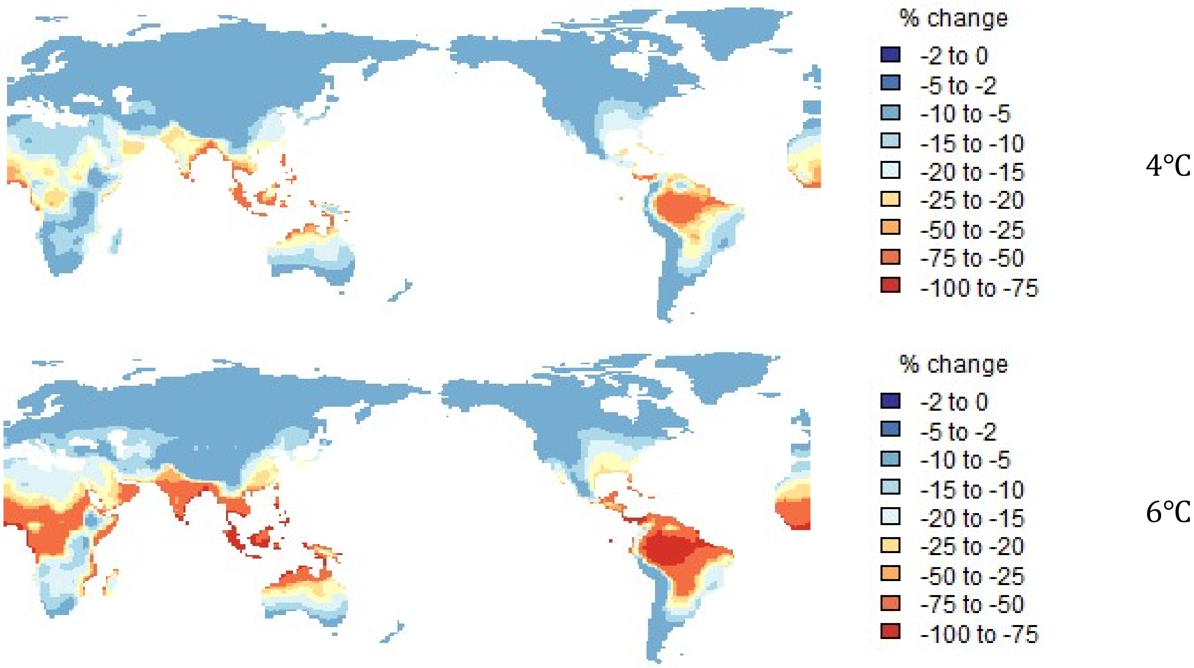

Figure 1. Climate change impact on Labor capacity for ESI-400W

Table 2. Labor shocks calculated for South and East Asia (SEA).

Reg	Function	Scenario	Labor	Activity	Lower	Median	Upper
SEA	ESI	5C	Agricultural and Unskilled	Construction	-4.1	-17.1	-36.3
SEA	ESI	5C		Manufacturing	-0.7	-3.6	-8.4
SEA	ESI	5C		Services	-1.7	-7.8	-17.3
SEA	ESI	5C	Service/Shop workers	Construction	-0.3	-2.0	-5.5
SEA	ESI	5C		Manufacturing	-0.2	-1.5	-4.2
SEA	ESI	5C		Services	-0.6	-3.4	-9.2
SEA	ESI	5C	Technicians and Professional	Construction	-0.1	-1.0	-3.0
SEA	ESI	5C		Manufacturing	-0.1	-1.0	-3.0
SEA	ESI	5C		Services	-0.2	-1.0	-3.1
SEA	ESI	5C	Officials and Managers	Construction	0.0	-0.3	-1.0
SEA	ESI	5C		Manufacturing	0.0	-0.3	-0.8
SEA	ESI	5C		Services	0.0	-0.2	-0.7

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