Global Economic Impact of Wildfire Smoke

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Abstract

In addressing the escalating threat of wildfires and their associated smoke, this study examines the global economic impact, with a focus on labor supply dynamics. Current issues like the increase in extreme weather events due to climate change. Wildfires, emerging as significant hazards, disseminate health-endangering pollutants through their smoke, emphasizing the need for this research. Our data encompasses a comprehensive analysis of 50 regions and 26 sectors. We use the GTAP 11 database and GTAP-AEZ extension for this analysis. We integrate this with health impact data from Xu et al. (2023) and mortality risk data across various studies. The methodology involves recalculating the additional labor supply shock compared to the business-as-usual (BAU) scenarios, employing the GTAP-RD model for dynamic labor supply impact analysis. Our findings from the period 2018 to 2050, using 2017 as a baseline, reveal stark regional differences in the economic effects of wildfire smoke. Notably, regions with higher Human Development Index scores, such as the United States and the European Union, exhibit comparatively modest reductions in projected GDP growth under scenarios involving fire smoke. In contrast, regions with lower HDI scores, particularly in West Africa, face more severe economic impacts.

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1 Introduction

In recent years, the world has witnessed an alarming increase in extreme weather events, a trend largely attributed to ongoing climate change. The Intergovernmental Panel on Climate Change (IPCC) in its 2023 report underscores the growing frequency and intensity of these events. Among them, wildfires have emerged as a particularly significant threat, with profound implications for both natural ecosystems and human communities (Moritz et al., 2014). A critical aspect of this threat is wildfire smoke, laden with harmful pollutants such as PM2.5 and O3 (Liu et al., 2015), which poses significant health risks. Numerous epidemiological studies have demonstrated the detrimental effects of these pollutants on human health, particularly concerning the respiratory system.

Recent research efforts have begun to unravel the economic implications of wildfire smoke. For instance, studies like those conducted by Childs et al. (2022) reveal that wildfire smoke has been the predominant source of air pollution in the United States since 2015. Furthermore, microeconomic research has identified significant impacts of wildfire smoke on various economic sectors, including labor markets (Borgschulte et al., 2022), housing markets (McCoy & Walsh, 2018), and fiscal policies (Liao & Kousky, 2022). However, these regional and microeconomic analyses have limitations in fully capturing the global economic impact of wildfire smoke.

Wildfire smoke has a transboundary impact, spreading across national borders and affecting countries far from the fire's origin. This has indirect effects on the economies of neighboring nations, particularly their trading partners. The impact varies within a country, affecting different industries, regions, and income groups in diverse ways. This necessitates a broad analysis that includes the dynamics of supply chains, as disruptions from smoke can lead to widespread economic challenges. It's also important to consider the timing and duration of these impacts for a comprehensive economic assessment. Previously, wildfires were smaller, and studies focused on their immediate, local effects. Recently due to climate change leading to larger wildfires, there is a growing need for general equilibrium (GE) analysis, which examines the overall economy. This approach helps understand the larger-scale, long-term impacts of wildfires on an economy, extending beyond the localized areas directly affected.

To address the complex interactions between environmental changes and labor dynamics, our study leverages the GTAP 11 database, enriched with the GTAP-AEZ extension, covering a comprehensive landscape of 50 regions and 26 sectors. This robust dataset is complemented by critical insights into landscape fire smoke exposure, as delineated by Xu et al. (2023), and mortality risk assessments gleaned from various studies. Our analytical framework is designed to quantify the region-specific reductions in labor stemming from wildfire smoke. By recalculating additional labor supply shocks in comparison to the business-as-usual (BAU) scenarios, we dynamically model the labor supply impacts using the GTAP-RD framework. This approach provides a novel lens through which to examine the global economic consequences of wildfire smoke, a phenomenon increasingly pertinent in the context of climate change.

Our methodology is grounded in the latest advancements in economic modeling. We build upon the refined GTAP-v7 model, as outlined by Aguiar et al. (2022), with the year 2017 serving as our baseline. Recognizing the extensive ecological implications of fire smoke, we incorporate the GTAP-AEZ extension to capture the intricate dynamics between wildfire smoke exposure and ecosystem services. This integration allows for a nuanced assessment of the labor supply shock across diverse regions and sectors, capturing the diverse impact of wildfire smoke on the global economic landscape.

The preliminary findings of our study, spanning from 2018 to 2050 with 2017 serving as the baseline year, demonstrate significant variations in the economic impact of wildfire smoke across different regions. While countries with high and very high Human Development Index (HDI) scores like the United States and the European Union exhibit a relatively modest decrease in projected GDP growth under the "Fire Smoke" scenario, the effect is substantially more severe in regions characterized by lower HDI scores, such as Congo and other West African countries. This underscores the disproportionate economic burden imposed by wildfire smoke on less developed regions, highlighting the critical necessity for targeted policy interventions aimed at mitigating these disparities.

2 Data

2.1 GTAP Data Base

For our study, we use the latest version of the GTAP model, GTAP-v7 (Corong et al., 2017). We utilize the GTAP 11 database, as detailed by Aguiar et al. (2022), with 2017 serving as our base year. Considering the impact of wildfire smoke on ecosystem services, we augmented our analysis with the GTAP-AEZ extension. This database has been aggregated to encompass 50 regions and 26 sectors, as shown in **Table 1**. The rationale behind this aggregation strategy is twofold: to broaden the regional coverage beyond that of the previous version, which included 36 regions, and to incorporate more granular data on key countries. This expansion is undertaken to ensure our model remains computational feasibility while enhancing its effectiveness in analysis.

2.2 Landscape Fire Smoke and Health Impact Data

To evaluate the risks associated with exposure to fire smoke and its impact on mortality, we draw on the findings from Chen et al. (2021) and Xu et al. (2023). These studies primarily utilize the Global Fire Emissions Database (GFED), a comprehensive resource developed by RANDERSON et al. (2017)[1], which is recognized as the most extensive database of fire emissions globally. Furthermore, they enhance their analysis by incorporating data from local monitoring stations that track PM2.5 levels.

[1] Xu et al. cross validates GFED, FINN, GFAS, and QFED data sets.

From these studies, we extrapolate relative mortality risks and quantify the number of sick days for the 50 regions included in our research. Chen et al.'s work, which covers 43 regions, serves as the foundation for our assessment of mortality risks. We adjust their findings to align with the framework of our study, which includes 50 regions, as detailed in Table 1, column 1.

To estimate the impact of smoke exposure on labor supply due to sick leave, we start with the dataset provided by Xu et al.'s on "Annual Average Days Per Person Exposed to Significant Fire Air Pollution"[2]. Additionally, we draw upon findings from a Chilean study by (Chan et al., n.d.) (n.d.), which suggests a 2.6% reduction in labor supply for each additional day of smoke exposure. This reduction is uniformly applied across South American countries and adjusted for other regions, as shown in Table 1, column 2. By combining these metrics, we construct a 'Fire Smoke' scenario-specific dataset, as delineated in Table 3, column 3. This dataset illustrates the supplementary shock to labor supply in comparison to the BAU scenario, as modeled within the GTAP-RD framework using the GTAP 11 database. Subsequently, we incorporate this additional shock into the existing BAU labor supply projections to complete our dataset for analysis. These

[2] They define a substantial fire-sourced air pollution (SFAP) day based on certain criteria: (1) days where the daily average PM2.5 (inclusive of all sources) surpasses the World Health Organization (WHO) 2021 daily guideline value of 15 $\mu g/m^3$, with at least 50% attributed to fire-sourced PM2.5, and (2) days where the daily maximum 8-hour O3 (encompassing all sources) exceeds the WHO's 2021 daily guideline of 100 $\mu g/m^3$, with at least 50% derived from fire-sourced O3. To assess population exposure to SFAP.

combined data streams provide a robust foundation for evaluating the global economic and health effects of wildfire smoke exposure.

3 Method

3.1 Extra Labor Shock Compared to BaU

As documented by Chen et al. (2021) and Xu et al. (2023), labor supply shocks stem from both mortality risk and sick leave days. Leveraging their findings, we calculate a tailored labor supply shock specific to each region. For the sake of simplicity, we define Total Regional Labor Supply as the product of the number of healthy working days and the number of workers (Persons × Days). Therefore, the decrease in labor supply accounts for the combined effects of short-term sick leave and the long-term increase in mortality risk. Consequently, the percentage change in labor supply for region i can be expressed as follows:

$$\%\Delta \mathrm{Total}LaborReduction_i = \%\Delta Mortality_i + \mathrm{TotalWorkers}\ \cdot \lambda_{\mathrm{i}} \cdot Days_{\mathrm{nonfire}}$$

where λ_i signifies the coefficient that measures the impact of additional exposure days to fire smoke on sick leave for each region. While it would be ideal for λ_{i} to be region-specific, for ease of calculation we adopt a uniform value of 2.6% for ease of computation, as determined by the study of Chan et al. (2022). By combining this labor reduction due to sick leave with the relative mortality risk, we conduct a "Fire Smoke" experiment. This experiment entails applying the additional labor shock data from column 3, Table 1, against the BAU scenario to dynamically adjust the labor supply (*qe(ENDW, REG)*).

3.2 Shock Fire Smoke Induced Labor Supply in GTAP-AEZ-RD Model

To assess the impact of the shock, our initial step involves applying it exclusively to the base year for comparison. For instance, we compare data from 2017 with data from the same year but accounting for the fire smoke. However, we acknowledge that the magnitude of this impact is likely to escalate due to climate change. To simulate this progression, we implement the labor supply shock for different regions for an annual increase in the shock over time. In our adaptation of the GTAP-RD model (Aguiar et al., 2020), these shocks are integrated by altering the projections used in the baseline labor force assumption, which follows the SSP2 framework. This approach allows for a more realistic simulation of future labor force dynamics in the context of evolving environmental challenges.

4 Preliminary Results

In our simulation, we projected the period from 2018 to 2050, using 2017 as the baseline year. The additional labor supply shock resulting from fire smoke varies across regions, which consequently leads to different regional responses in terms of key economic indicators. Our preliminary analysis primarily focuses on GDP values. As illustrated in Figure 2, regions such as the United States and the European Union, characterized by high or very high HDI ratings, experience a relatively modest decline in projected growth percentage under the "Fire Smoke" scenario. Conversely, countries like Congo and other

West African nations face a considerably higher potential loss in projected GDP growth compared to the BAU scenarios. This suggests that the economic impact of fire smoke is more pronounced in regions with lower HDI scores, underscoring the need for targeted interventions and policy considerations to mitigate these adverse effects.

5 Discussion and Concluding Remarks

Our study stands as the pioneering effort to integrate the global health and labor supply impacts of fire smoke into regions defined by the GTAP-11 database. Notably, we are the first to employ the computable general equilibrium model (GTAP-RD) for simulations extending to 2050, offering insights into the global economic impact of wildfire smoke exposure. Recognizing the urgency of our findings, we also identify areas for future refinement and expansion.

Our primary objective is to develop a more comprehensive dataset through meta-analysis, particularly focusing on refining the λ_i for each region. This enhancement will enable more precise modeling of regional impacts. Additionally, we aim to refine the model further to gain a deeper understanding of the distribution of labor shocks in both the short and long term. This involves extending projections and incorporating other Shared Socioeconomic Pathways (SSP) scenarios.

Looking ahead, we envision broadening the scope of our research to make more substantial contributions to global-level estimates. This entails translating the health impact of wildfire smoke exposure into economic terms, thereby facilitating greater international cooperation on fire mitigation projects and climate change policymaking. Such advancements are crucial for informing and guiding effective policy responses to the growing challenges posed by climate change and its associated natural hazards.

6 References

Aguiar, A., Chepeliev, M., Corong, E., & Van Der Mensbrugghe, D. (2022). The Global Trade Analysis Project (GTAP) Data Base: Version 11. *Journal of Global Economic Analysis*, *7*(2), 1–37. https://doi.org/10.21642/JGEA.070201AF

Borgschulte, M., Molitor, D., & Zou, E. (2022). *Air Pollution and the Labor Market: Evidence from Wildfire Smoke* (Working Paper 29952). National Bureau of Economic Research. https://doi.org/10.3386/w29952

Chan, H. R., Pelli, M., & Arancibia, V. V. (n.d.). *Wildfires, Smoky Days, and Labor Supply*.

Chen, G., Guo, Y., Yue, X., Tong, S., Gasparrini, A., Bell, M. L., Armstrong, B., Schwartz, J., Jaakkola, J. J. K., Zanobetti, A., Lavigne, E., Nascimento Saldiva, P. H., Kan, H., Royé, D., Milojevic, A., Overcenco, A., Urban, A., Schneider, A., Entezari, A., … Li, S. (2021). Mortality risk attributable to wildfire-related PM2·5 pollution: A global time series study in 749 locations. *The Lancet Planetary Health*, *5*(9), e579–e587. https://doi.org/10.1016/S2542-5196(21)00200-X

Corong, E. L., Hertel, T. W., McDougall, R., Tsigas, M. E., & Mensbrugghe, D. van der. (2017). The Standard GTAP Model, Version 7. *Journal of Global Economic Analysis*, *2*(1), Article 1. https://doi.org/10.21642/JGEA.020101AF

Intergovernmental Panel on Climate Change (IPCC). (2023). *Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. https://doi.org/10.1017/9781009157896

Liao, Y. (Penny), & Kousky, C. (2022). The Fiscal Impacts of Wildfires on California Municipalities. *Journal of the Association of Environmental and Resource Economists*, *9*(3), 455–493. https://doi.org/10.1086/717492

Liu, J. C., Pereira, G., Uhl, S. A., Bravo, M. A., & Bell, M. L. (2015). A systematic review of the physical health impacts from non-occupational exposure to wildfire smoke. *Environmental Research*, *136*, 120–132. https://doi.org/10.1016/j.envres.2014.10.015

McCoy, S. J., & Walsh, R. P. (2018). Wildfire risk, salience & housing demand. *Journal of Environmental Economics and Management*, *91*, 203–228. https://doi.org/10.1016/j.jeem.2018.07.005

Moritz, M. A., Batllori, E., Bradstock, R. A., Gill, A. M., Handmer, J., Hessburg, P. F., Leonard, J., McCaffrey, S., Odion, D. C., Schoennagel, T., & Syphard, A. D. (2014). Learning to coexist with wildfire. *Nature*, *515*(7525), 58–66. https://doi.org/10.1038/nature13946

RANDERSON, J. T., VAN DER WERF, G. R., GIGLIO, L., COLLATZ, G. J., & KASIBHATLA, P. S. (2017). *Global Fire Emissions Database, Version 4.1 (GFEDv4)*. 1925.7122549999906 MB. https://doi.org/10.3334/ORNLDAAC/1293

Xu, R., Ye, T., Yue, X., Yang, Z., Yu, W., Zhang, Y., Bell, M. L., Morawska, L., Yu, P., Zhang, Y., Wu, Y., Liu, Y., Johnston, F., Lei, Y., Abramson, M. J., Guo, Y., & Li, S. (2023). Global population exposure to landscape fire air pollution from 2000 to 2019. *Nature*, *621*(7979), 521–529. https://doi.org/10.1038/s41586-023-06398-6

7 Table

Table 1. Extra Health Risks and Labor Shock with Fire Smoke compared with BAU for 50 Aggregated Regions

Aggregated Regions	Extra Relative Risk of Mortality compared to BaU (%)	Extra Labor Working Hours Reduction (%)	Total Extra Labor Shock (%)
Australia and New Zealand	0.200	0.6741	0.874
China and Hong Kong	3.000	0.4761	3.476
Japan	2.700	0.4761	3.176
Republic of Korea	3.033	0.4761	3.509
Mongolia	3.000	0.4761	3.476
Indonesia	1.100	0.4761	1.576
Malaysia	1.100	0.4761	1.576
Philippines	0.800	0.4761	1.276
Thailand	1.600	0.4761	2.076
Viet Nam	0.900	0.4761	1.376
Rest of Southeast Asia	1.743	0.4761	2.219
Bangladesh	1.743	0.4761	2.219
India	2.000	0.4761	2.476
Nepal	2.000	0.4761	2.476
Pakistan	2.000	0.4761	2.476
Rest of South Asia	2.000	0.4761	2.476
Canada	-0.800	0.8613	0.061
United States of America	1.000	0.8613	1.861
Mexico	0.200	0.8613	1.061
Argentina	4.000	2.6000	6.600
Brazil	1.100	2.6000	3.700
Chile	3.300	2.6000	5.900
Colombia	2.800	2.6000	5.400
Peru	-2.500	2.6000	0.100
Costa Rica	6.900	2.6000	9.500
Honduras	1.414	2.6000	4.014
Rest of South America and Caribbean	2.257	2.6000	4.857
European Union	4.438	0.1230	4.561
United Kingdom of Great Britain and Northern Ireland	2.300	0.1230	2.423
Norway	1.600	0.1230	1.723

Rest of European Free Trade Area	3.350	0.1230	3.473
Rest of Europe	2.300	0.1230	2.423
Rest of Centra Asia	1.800	0.1230	1.923
Russia	1.800	0.1230	1.923
Middle East	1.800	0.1230	1.923
Turkey	1.800	0.1230	1.923
Middle East and North Africa	1.800	0.1230	1.923
Nigeria	1.800	3.5683	5.368
Democratic Republic of the Congo	1.800	3.5683	5.368
Rest of Western and Central Africa	1.800	3.5683	5.368
Gabon	1.800	3.5683	5.368
Ethiopia	1.800	3.5683	5.368
Kenya	1.800	3.5683	5.368
United Republic of Tanzania	1.800	3.5683	5.368
Uganda	1.800	3.5683	5.368
Botswana	1.800	3.5683	5.368
Namibia	1.800	3.5683	5.368
South Africa	1.800	3.5683	5.368
Rest of East and Southern Africa	1.800	3.5683	5.368
Rest of the World	3.400	0.1681	3.568

8 Figures

Figure 1: Difference in Relative Health Risk and Labor Supply Shock for "Fire Smoke" Scenario vs. Business as Usual (BAU) Scenario

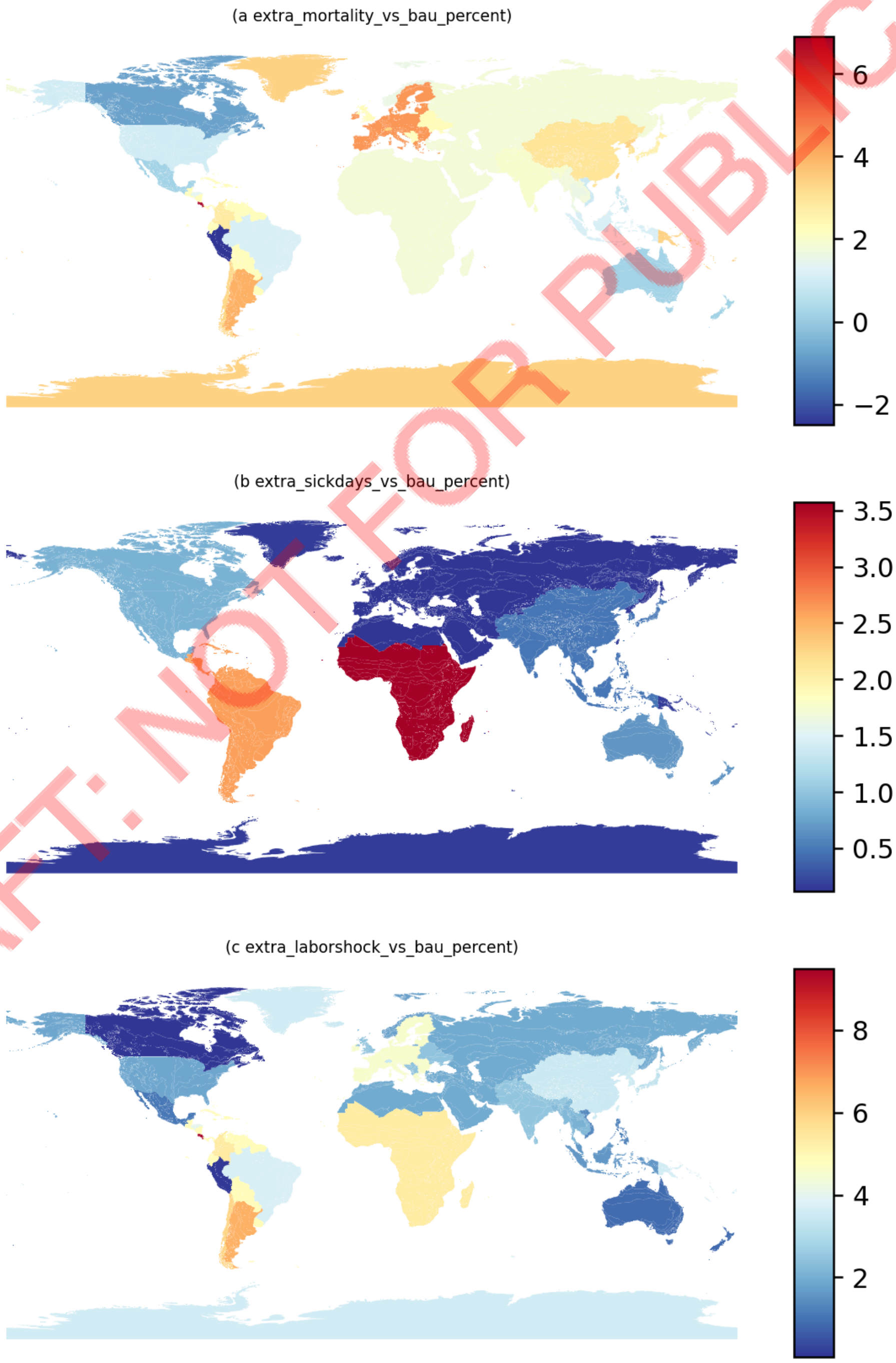

Figure 2: Difference in Projected GDP Growth Percentage Using Fisher Index ($vgdpfisher$) for Scenarios with Fire Smoke and Business-as-Usual (BAU)