



## Prosperity Insight Series

# CLIMATE AND EQUITY:

## A Framework to Understand Welfare Impacts and Guide Policy Action

Ruth Hill, Trang Nguyen, Miki Khanh Doan



WORLD BANK GROUP



# CLIMATE AND EQUITY:

---

## A Framework to Understand Welfare Impacts and Guide Policy Action

Ruth Hill, Trang Nguyen, Miki Khanh Doan<sup>1</sup>

---

1. The American Economic Association author randomization tool was used to randomize author names.

This paper builds on an earlier policy brief to which Ben Brunckhorst and Ghazala Mansuri also contributed. It has benefited from comments by Richard Damania, Alan Fuchs, and Maria Ana Lugo, as well as suggestions by Haroon Bhorat, Francois Bourguignon, Shanta Devarajan, Francisco Ferreira, Susanna Gable, Stephane Hallegatte, Reema Hanna, Ravi Kanbur, Nora Lustig, Danielle Resnick, and Florencia Torche. This paper has also benefited from many staff in the World Bank's Poverty and Equity Global Practice who provided inputs and comments through a series of presentations (in particular, Javier Baez, Ana Maria Munoz Boudet, Sandra Baquie, Carlos Rodriguez Castelan, Lourdes Rodriguez Chamussy, Alejandro de la Fuente, Daniel Valderama Gonzalez, Johannes Hoogeveen, Gabriela Inchauste, Rinku Murgai, Pierella Paci, Lokendra Phadera, Ambar Narayan, Reena Badiani, Monica Robayo, Jorge Luis Castaneda Nunez, Samuel Rodriguez, Sailesh Tiwari, Ailin Tomio, Matthew Wai-Poi, and Salman Zaidi). It was prepared under the guidance of Luis Felipe Lopez-Calva and Benu Bidani.

© 2024 International Bank for Reconstruction and Development / The World Bank  
1818 H Street NW  
Washington DC 20433  
Telephone: 202-473-1000  
Internet: [www.worldbank.org](http://www.worldbank.org)

This work is a product of the staff of The World Bank with external contributions. The findings, interpretations, and conclusions expressed in this work do not necessarily reflect the views of The World Bank, its Board of Executive Directors, or the governments they represent.

The World Bank does not guarantee the accuracy, completeness, or currency of the data included in this work and does not assume responsibility for any errors, omissions, or discrepancies in the information, or liability with respect to the use of or failure to use the information, methods, processes, or conclusions set forth. The boundaries, colors, denominations, and other information shown on any map in this work do not imply any judgment on the part of The World Bank concerning the legal status of any territory or the endorsement or acceptance of such boundaries.

Nothing herein shall constitute or be construed or considered to be a limitation upon or waiver of the privileges and immunities of The World Bank, all of which are specifically reserved.

#### **Rights and Permissions**

The material in this work is subject to copyright. Because The World Bank encourages dissemination of its knowledge, this work may be reproduced, in whole or in part, for noncommercial purposes as long as full attribution to this work is given.

Any queries on rights and licenses, including subsidiary rights, should be addressed to World Bank Publications, The World Bank Group, 1818 H Street NW, Washington, DC 20433, USA; fax: 202-522-2625; e-mail: [pubrights@worldbank.org](mailto:pubrights@worldbank.org).

Cover photo: © brazzo / iStock. Further permission required for reuse.

Document photos: © Ivan Bruno / iStock. Further permission required for reuse, © Lingbeek / iStock. Further permission required for reuse, © georgeclerk / iStock. Further permission required for reuse

Cover design: Anatol Ursu, <https://www.behance.net/olywebart>

# Abstract

Reducing the impact of climate change on poor and vulnerable households is essential for hastening poverty reduction. In thinking about policies that do this, it is useful to apply the same hazard, exposure, and vulnerability framework that is often used to understand the physical impacts of climate change and add the non-climate benefits and costs to households that these policies can also bring. Policies that reduce hazards and/or vulnerability while bringing non-climate benefits should be prioritized where possible. However, some development policies that bring non-climate benefits, particularly in higher-income and higher-growth countries, may increase emissions by enough to worsen future hazards, so their emissions impact needs to be managed with compensating actions. Policies that reduce the hazards faced by poor households are needed, and the non-climate cost of these policies on poor people should be minimized or compensated where it cannot be avoided.



# TABLE OF CONTENTS

|                                                                               |           |
|-------------------------------------------------------------------------------|-----------|
| <b>Executive Summary</b>                                                      | <b>1</b>  |
| <b>1. Background</b>                                                          | <b>3</b>  |
| <b>2. The Welfare Impacts of Climate</b>                                      | <b>5</b>  |
| 2.1. The Asset-Based Framework                                                | 5         |
| 2.2. The Role of Climate in Determining Household Welfare                     | 7         |
| 2.3. The Impact of Climate Change on Welfare                                  | 12        |
| 2.4. Measuring the Welfare Impacts of Climate Change                          | 13        |
| <b>3. The Welfare Impacts of Climate Policies</b>                             | <b>23</b> |
| 3.1. The Impact of Climate Policies on Welfare                                | 23        |
| 3.2. Policies with Minimal Trade-off                                          | 28        |
| 3.3. Addressing Trade-offs: Reducing Vulnerability at a Cost to Income Growth | 32        |
| 3.4. Addressing Trade-offs: Reducing Hazards While Minimizing Welfare Costs   | 34        |
| 3.5. Cross-Border Issues and Climate Justice                                  | 43        |
| <b>References</b>                                                             | <b>45</b> |





## EXECUTIVE SUMMARY

Reducing the impact of climate change on poor and vulnerable households is essential for hastening poverty reduction. Climate change disproportionately affects poor and vulnerable people whose livelihoods often depend on natural resources and whose lack of access to savings, credit, and insurance makes hazards more costly.

To guide policy action, this document sets out a framework for thinking about the relationship between climate and poverty, and how climate change and climate policies affect household welfare. It also provides a review of the analytical methods and tools that can be used to quantify the risks climate and climate change pose to welfare, and the impacts of climate action on welfare.

The framework uses an asset-based approach to examine how climate outcomes affect household income and consumption, and how households use assets and markets to cope with climate shocks. Poor households often rely on natural resources for their livelihoods, which makes their incomes more dependent on weather and thus highly susceptible to changes in the climate. Additionally, the lack of capital that accompanies a life in poverty makes hazards more costly. They are less likely to be able to rely on savings, access to credit, or insurance to manage their losses of income or assets. This paper also adapts the hazard, exposure, and vulnerability framework to explore how climate change and policies impact welfare through three channels: the hazard distribution, changes in exposure and vulnerability, and other benefits or costs to households that do not rely on climate outcomes. The net welfare impact of policy will vary across people.

Policies that address climate hazards or reduce exposure and vulnerability and bring non-climate benefits for poor and vulnerable people--so-called double or triple wins--should be prioritized. Some examples of triple wins include certain climate-smart agricultural practices, sustainable forest management, investments in clean energy access, and reducing inefficiencies in trade. These actions have minimal trade-offs in achieving progress on both climate goals and development outcomes.

In many cases, trade-offs are present in the short run. For example, rising energy prices and job losses in carbon-intensive sectors can significantly affect poorer and more vulnerable communities. Transitioning to renewable energy sources, for instance, can impose costs on communities that rely on fossil fuel industries. Addressing the trade-offs inherent in climate policies requires a nuanced understanding of the diverse impacts that these policies can have across different populations and time horizons. While the long-run benefits are clear, it is important to measure and manage trade-offs that exist in the short to medium term and design compensatory actions to ensure an equitable transition. Policy packages will often be required to ensure that both climate and poverty targets are simultaneously met.



# 1<sub>C</sub>

## BACKGROUND

The World Bank has adopted a new vision statement: to end poverty on a livable planet. The mission underscores the relationship between poverty and climate objectives. The livelihoods of poor households are often particularly reliant on their environment and the natural capital to which they have access. Both aspects of the mission are currently under threat. Three decades of progress

on poverty reduction that saw 1 billion people move out of poverty came to a halt in 2020. Climate change poses a significant threat to the lives and livelihoods of poor and vulnerable people. Urgent action is necessary to end extreme poverty and prevent catastrophic climate-related hazards and biodiversity loss.

However, actions that are particularly good for one objective may not be as effective, and could even be detrimental, for the other. Understanding and managing these trade-offs is essential for success. This paper presents a framework for thinking about the relationship between climate and poverty, and the channels through which climate action impacts household welfare. This framework is then used to highlight the synergies and trade-offs in meeting climate and poverty and equity objectives, along with analytical methods and tools that can be used to quantify the trade-offs where possible. The goal is to provide a primer to microeconomists working on welfare analysis of climate change and climate action that explains key concepts, provides a rubric for thinking through the issues, and describes available tools to use. At various points, a review of the literature is also provided (or review pieces referenced), but the goal of the paper is not to provide a comprehensive review of the literature. Although written primarily for an internal World Bank audience, the paper may have interest beyond that. An earlier policy brief discusses the same framework and policy guiding principles (Brunckhorst et al., 2023).

The focus of the framework is on the economic impacts of climate change and climate action. However, it is important to note that much of the welfare impact of climate change and related extreme events comes through loss of life and adverse effects on physical and mental health, particularly in poor places with fewer means to cope. Natural disasters intensified by climate change can cause significant loss of life. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report projects 250,000 deaths in excess per year by 2050 attributable to climate change due to heat, undernutrition, malaria, and diarrheal disease (IPCC, 2023a). Africa accounts for more than half of this projected excess mortality.



## 2c



# THE WELFARE IMPACTS OF CLIMATE

## 2.1. The Asset-Based Framework

We start the framework by focusing on a household and its ability to earn income and increase its welfare. The ability of a household to earn income depends on its ability to accumulate and use assets, and the return the household earns when these

assets are used to generate income (López-Calva & Rodríguez-Castelán, 2016). Household income is determined by these factors, as well as by any taxes paid and transfers and subsidies received.

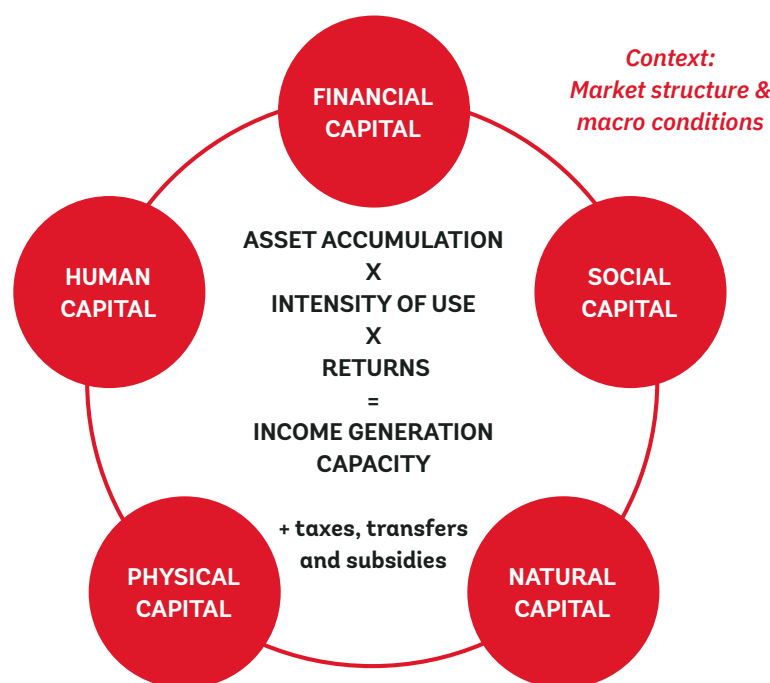
A household can accumulate and use many kinds of assets. They can be grouped into five main categories: financial (cash in hand, bank accounts, net loans outstanding), physical (agricultural tools, livestock), human (knowledge, skills, health), social (networks, norms, social trust), and natural (land, biodiversity). Income growth comes from investing in and protecting these assets, and from increasing the returns to these assets. The returns to assets can be increased through technological change and through investments and policies that impact the context—the market structure and macro conditions—in which a household lives and works. Figure 1 illustrates the core concept of this asset-based framework.

There are two important points to note from the asset-based framework for a discussion on the relationship between climate and poverty. First, poor households often engage in livelihood activities that heavily rely on the use of natural capital, such as farming, pastoralism, and fishing. Consequently, climate change, such as an increase

in hot days, extreme rainfall, and storms, imposes significant costs on the income-earning capacity of poor people (Birkmann et al., 2022).

Second, the impacts of climate change on welfare—whether that is increased risk of extreme events or gradual increase in temperatures, sea level rise or changes in wetness—depend on a household's assets and the context in which the household finds itself. For example, households residing near healthy mangrove ecosystems (that is, households with more natural capital) have lower coastal flood risks (Gijsman et al., 2021). Households with higher levels of education (that is, households with more human capital) are better equipped to adapt their livelihood activities, households with savings (that is, more financial capital) are more capable of restarting businesses, and households with access to remittances (that is, more social capital) can finance immediate consumption after a weather shock (Mohapatra et al., 2012; Jack & Suri, 2014; Rahman & Akter, 2014; Anik et al., 2018).

**Figure 1:** Asset-based Framework



Source: López-Calva and Rodríguez-Castelán, 2016.

Given the focus of this framework on the impact of climate on welfare, we focus on the welfare that is determined by climate outcomes. The welfare of household  $i$  living in location  $k$  at time  $t$ ,  $W_{ikt}$ , can be decomposed into two components: the part determined by climate outcomes,  $W_{ikt}^C$ , and the part independent of climate,  $W_{ikt}^{NC}$ . As the discussion in this subsection has underscored, both components depend on the environmental and socioeconomic context,  $ESEC$ , and the household's accumulation

and use of assets,  $X$ . For  $W_{ikt}^C$ , then, which is our interest, we can write:

$$W_{ikt}^C = f(ESEC_{kt}, X_{ikt}, c_{kt}), \quad (\text{Eq. 1})$$

where  $f(\cdot)$  captures how exposure to a given weather outcome,  $c_{kt}$ , translates into household's welfare given  $ESEC_{kt}$  and  $X_{ikt}$ . The general functional form allows for flexibility in capturing interactions across and within each component.

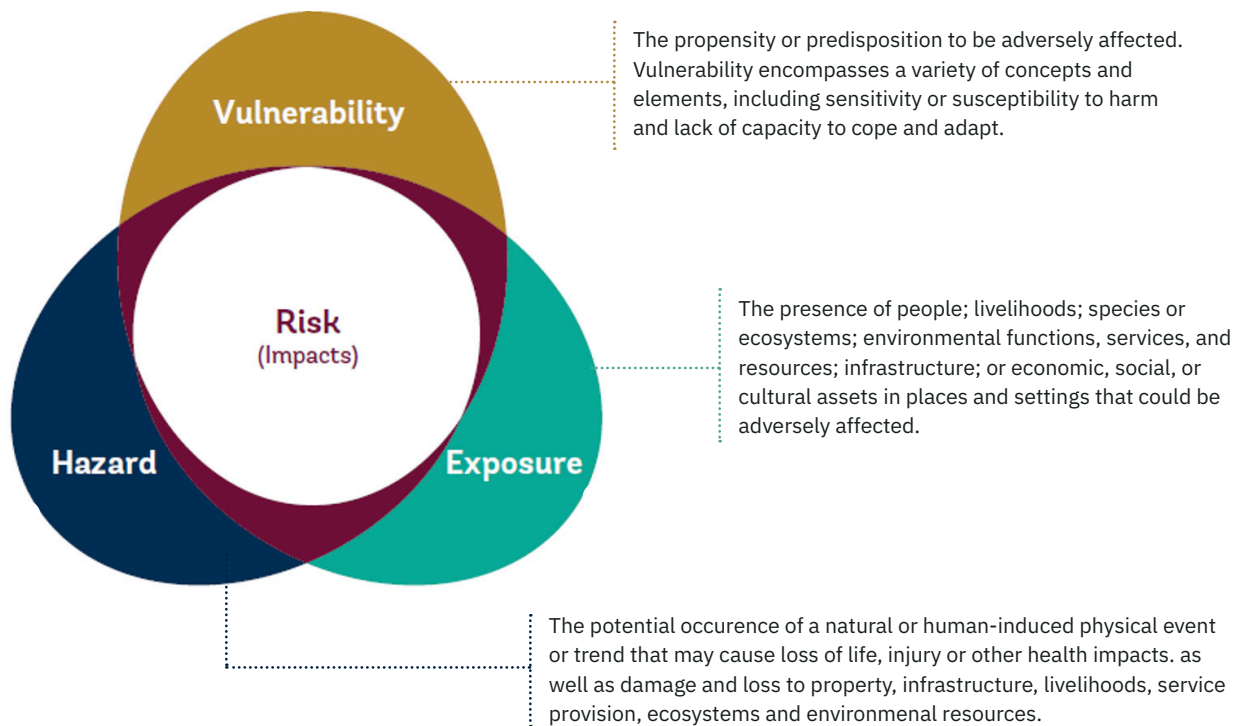
## 2.2. The Role of Climate in Determining Household Welfare

### Hazard, Exposure, and Vulnerability Framework

In this section, we focus on further unpacking  $W_{ikt}^C$ . To do this, we use the hazard, exposure, and vulnerability framework that is commonly used in modeling the impact of climate events. Figure 2 provides an overview of this framework, incorporating the definitions of these components

outlined by the IPCC. *Hazard* refers to a potential adverse weather event that may affect people's welfare. *Exposure* captures the number of people or assets exposed to a given hazard. *Vulnerability* is the extent to which a hazard adversely impacts a household's welfare.

**Figure 2:** Hazard, Exposure, and Vulnerability Framework



Source: IPCC, 2023b.

In the notation of equation (1),  $c_{kt}$  reflects the weather outcome experienced by the household at time  $t$  and thus reflects exposure to a given hazard. Vulnerability is the marginal change in welfare experienced by a household in response to a change in the magnitude of the weather outcome:

$$Vulnerability = \frac{\partial f(ESEC_{kt}, X_{ikt}, c_{kt})}{\partial c_{kt}} \quad (\text{Eq. 2})$$

Two aspects of the definition are worth noting. First, there is a difference between how *vulnerability* is defined in the IPCC definition and how it has been used in the poverty measurement literature (see Hoddinott and Quisumbing [2010] for a review). In the poverty measurement literature, *vulnerability* is usually defined as the likelihood that a household's welfare,  $W_{ikt}$ , falls below a minimum level of consumption given by the poverty line. It is related to the measure given in equation (2) in that if the vulnerability of  $W_{ikt}$  to  $c_{kt}$  is high, then it is more likely that  $W_{ikt}$  will fall below a poverty line in expectation, but it is a different concept. Given there is an increasing consensus on the use of vulnerability as part of the hazard, exposure, and vulnerability framework, we use *vulnerability* as defined in equation (2) in the rest of this note.

Second, the vulnerability of a household to a climate event does not refer only to the initial impact of the event on assets or income; it also reflects the ability of a household to protect its welfare from that impact. This is reflected in the IPCC definition, where *vulnerability* includes both “the sensitivity or susceptibility to harm” and “the lack of capacity to cope and adapt.” For example, a household may experience a loss in agricultural income from a weather event. The size of that agricultural income loss will depend on the ability of the household to protect yields from a drought by using irrigation, say, or its ability to move cattle to protect them from

loss in a flood. If agricultural income is lost, the size of the total income loss will depend on whether the household is able to compensate for losses in agricultural income by earning income from other activities. If total income is lost, the degree to which this impacts consumption will depend on its ability to smooth consumption through borrowing and saving or receiving remittances from friends and family. If welfare is being defined by consumption, all these aspects of a household's characteristics will determine its vulnerability to weather shocks. In terms of the notation of equation (2) the cross-derivative  $\frac{\partial^2 f(ESEC_{kt}, X_{ikt}, c_{kt})}{\partial c_{kt} \partial X_{ikt}}$  identifies how much vulnerability depends on household circumstances.

The setup discussed so far has good grounding in the applied microeconomic literature and is the same setup used by Hsiang et al. (2019) as they consider the distribution of environmental damages. However, to properly align equation (1) with the framework set out in figure 2, we need to switch from looking at the welfare impact of a particular weather event that a household has been exposed to,  $c_{kt}$ , to looking at “the potential occurrence” of a weather event,  $h(c_{kt})$ , as indicated by the definition of *hazard* in figure 2. In other words, instead of examining the ex-post welfare effects of a weather event, we need to think about the expected impact of weather events, and how this expected impact changes as the probability distribution of weather events changes (climate change). For a risk neutral person, this can be written as

$$E[W_{ikt}^c] = \int_{min}^{max} h(c_{kt}) f(ESEC_{kt}, X_{ikt}, c_{kt}) dc, \quad (\text{Eq. 3})$$

where  $E[W_{ikt}^c]$  is the expectation of  $W_{ikt}^c$  and  $h(c_{kt})$  represents the probability distribution of possible realized weather outcomes in location  $k$  (that is, the climate). In reality, people are risk averse and derive lower utility from extreme outcomes and expected welfare is given as:

$$\int_{\min}^{\max} h(c_{kt}) u(ESEC_{kt}, X_{ikt}, c_{kt}) dc,$$

where  $u(.)$  is the utility derived from the welfare outcome achieved when the weather event is  $c_{kt}$ .

An example of  $h(c_{kt})$  would be the distribution of potential number of days with average temperatures above 30 degrees Celsius in a year in a given location, with the hazard referring to the right tail of the distribution where the number of days in this category significantly affect human's living and working conditions.

Hazard, exposure, and vulnerability differ across households. The distribution of hazards is partially determined by  $ESEC_k$ , which, in turn, is shaped by households' accumulation and use of assets. Exposure and vulnerability to a specific hazard also vary across households because these two components are determined by the context and households' accumulation and use of assets. When climate shocks occur, they tend to have a larger impact on households that have less access to markets, capital, and basic services (Dercon, 2004; Lybbert et al., 2004).

With this basic setup in place, the following subsections indicate how the framework can be extended to reflect other aspects of the relationship between welfare and climate.

### Indirect Effects of Weather Conditions

Equation (3) indicates that the welfare of a household in location  $k$  is dependent on the weather realized in location  $k$ . However, it is quite possible that the weather conditions in another location impact  $W_{ikt}$  through their impacts on markets. Weather conditions can disrupt markets or reduce supply of food or other commodities and impact prices. While Hallegatte et al. (2016) suggest this

will be a large part of the welfare impact of climate change, Artuc et al. (2023), which specifically model trade between locations, suggest that this is unlikely to be a large impact. However, for a given climate shock it is quite possible that interruptions in nearby markets and price impacts occur.

This can be represented in equation (3) in two ways. First,  $h(.)$  can be a matrix of weather outcomes across places that may impact a household in location  $k$ . Alternately, the climate shock in location  $k$  can refer to weather-induced changes in prices, even if the weather conditions have occurred elsewhere.

### Costly Income Smoothing

The subtler welfare impact of extreme weather events occurs not when disasters strike but in the costly behavior driven by the anticipation of shocks that households are ill placed to cope with (uninsured risk). The direct impact of a calamity on well-being is the visible, headline-grabbing way that conflict or poorly managed disasters set back progress. However, the persistent impact of uninsured risk on household behavior every year—regardless of whether the feared event occurs—is arguably the larger constraint to accelerating poverty reduction. In Zimbabwe, this was found to be twice as large an impact on income growth (Elbers et al., 2007).

When households face risk, their rational response is to act to avoid it. When households cannot manage the risk in their environment, they may eschew investments and livelihood strategies (such as cultivation of high-risk, high-return crops) that offer great reward but leave them too exposed to the elements of nature, the economic ups and downs of a weak economy, or the uncertain behavior of others.

A number of well-identified studies across contexts show that when households have higher access to climate risk management instruments, there is a 15–30 percent increase in investment regardless of whether shocks occur (Mobarak & Rosenzweig [2013] for rainfall index insurance in India; Elabed & Carter [2014] for area yield insurance in Mali; Karlan et al. [2014] for rainfall index insurance in Ghana; Cai et al. [2015] for swine insurance in China; Cai [2016] for area-yield insurance in China; Fuchs & Wolff [2016] for rainfall index insurance in Mexico; Jensen et al. [2017] for livestock insurance in Kenya; Hill et al. [2019] for rainfall and area yield insurance in Bangladesh; Bulte et al. [2020] for multiperil crop insurance in Kenya; Stoeffler et al. [2022] for area yield in Burkina Faso). When farm households have an opportunity to insure their crops, investment in agricultural inputs goes up: in Ghana, spending on inputs rose by 88 percent, from US\$375 to US\$705 (Karlan et al., 2014); in Mali, spending on inputs increased by 14 percent (Elabed & Carter, 2014). The returns to these inputs vary in any given year based on weather conditions and prices (Rosenzweig & Udry, 2016), but even assuming a relatively low average return to input use, these increases amount to an average increase in income growth of 1–9 percent a year—enough to move many of these farmers out of poverty and to offset the losses associated with one-in-five-year events.

Equation (3) considers the welfare of household  $i$  at one point in time, but in reality, welfare is maximized across multiple periods (Deaton, 1997):

$$W_{ik}^C = E_t \sum_{t=1}^T w_{ikt}^C,$$

where  $w_{ikt}^C$  is welfare in one period. When households are unable to insure welfare from shocks to income, the amount that is invested in production decisions can be less than that

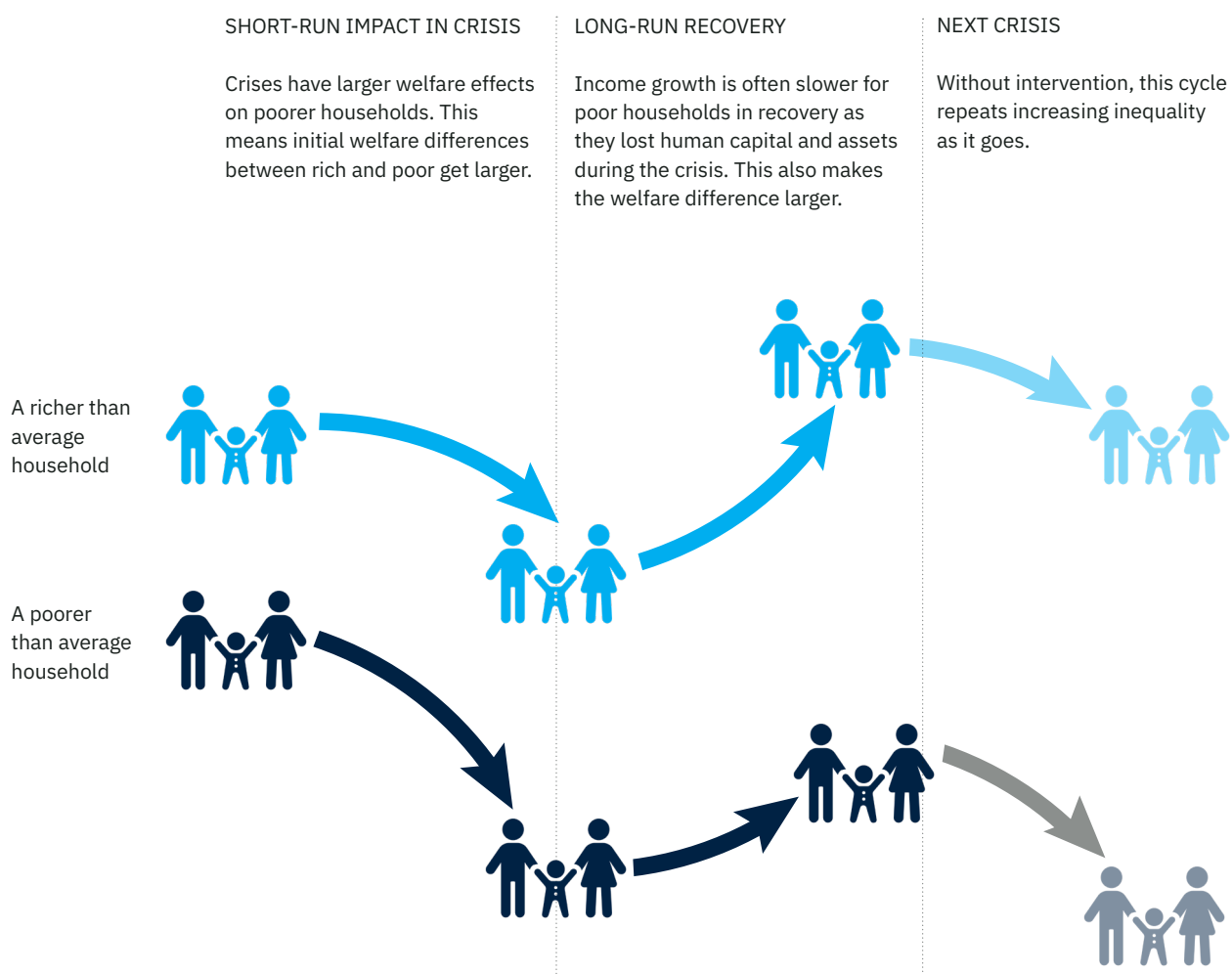
predicted by a profit maximization strategy every period (Sandmo, 1971).

### Long-Run Impacts and the Concept of Resilience

Much evidence points to the fact that shocks cast a long shadow on welfare. Income shocks increase the probability of being infected by the human immunodeficiency virus (Burke et al., 2015). When a household experiences a shock, investments in education and nutrition are reduced, and this increases a child's likelihood of being in poverty as an adult. The impact of nutritional and educational shocks on incomes earned as an adult is substantial, including a 3 percent reduction in annual earnings in Ethiopia, 20 percent lower wages in Burundi, and 14 percent lower lifetime earnings in Zimbabwe (Alderman et al., 2006; Bundervoet et al., 2009). Shocks can matter even before one is born: in Bangladesh, in utero exposure to a tornado increased the probability of low birth weight and decreased birth length (Gunnsteinsson et al., 2022); in Mozambique, those exposed to drought in utero had fewer years of schooling (Baez et al., 2017).

Not only do the initial impacts of climate events vary by household characteristics, but so does the ability to recover from shocks. This is depicted in figure 3, which indicates how poorer households may experience both larger losses in a crisis and slower recovery from a crisis.

**Figure 3:** Resilience is Often Lower for Lower-Income Households



Source: Hill and Narayan, 2020.

Large and sustained income losses require households to use coping mechanisms with long-run impacts: inadequate nutrition in first 500 days of life, high rates of indebtedness, and, at times, the loss of productive assets and permanent withdrawal of children from schools. Past evidence suggests that reducing food consumption is most frequently used as a coping strategy after a fast onset shock, whereas sale of productive assets seems to be mainly used by households as a coping strategy of last resort. Dercon (2004) finds that 8 percent of households affected by the famine in Ethiopia in the mid-1980s reduced food consumption, 39 percent sold valuables (on average 29 percent of livestock holdings were liquidated), 7 percent migrated in distress, and 11 percent had at least one member go to a feeding camp. This ordering of the prevalence of coping strategies was constant in every village, even though the severity of harvest failure varied across villages. In Burkina Faso in 1984, combined livestock sales offset between 15 percent and 30 percent of the income losses resulting from drought during this period, while more than half of the rainfall-induced crop

losses were passed on to reduced consumption (Fafchamps et al., 1998; Kazianga & Udry, 2006). In southern Ethiopia, drought did not trigger the sale of livestock, and in northern Kenya, households chose to protect the assets they had by reducing food intake and energy levels (Lybbert et al., 2004; McPeak & Barrett, 2001).

A household that is less vulnerable or more resilient will recover more quickly; a household that is more vulnerable (or less resilient) will recover more slowly. In equation (3), this can be represented by considering welfare at time  $t$  to be dependent also on weather conditions in a prior period  $t-n$ . The size of  $n$  to consider will depend on the context. The concept of resilience refers to this ability of households to recover in a timely manner. Although resilience used to be used to capture the notion of “bouncing back,” it has over time become broader, taking into account the process by which households recover, the degree to which shocks can be anticipated and managed (Lavell et al., 2012).

### 2.3. The Impact of Climate Change on Welfare

Climate change is altering the distribution of hazards faced by individuals in all locations in the world. The probability of extreme events—“tail” events that reflect events in the tails of the hazard distribution—is expected to increase. This includes an increasing likelihood of catastrophic floods, drought, heat waves, and cyclones. Additionally, the average weather is expected to change with temperatures increasing everywhere and wetness increasing in some places.

All of these changes can be reflected in a change in the distribution  $h(.)$ . The change in welfare that a change in the climate brings is thus given by

$$\Delta E[W_{ikt}^c] = \int_{min}^{max} [h'(c_{kt}) - h(c_{kt})] f(ESE c_{kt}, X_{ikt}, c_{kt}) dc, \quad (\text{Eq. 4})$$

assuming everything else stays equal. Where  $h'(.)$  is the probability distribution of weather outcomes under climate change.

There are six aspects to the changing climate that will impact welfare:

- i. The frequency and intensity of extreme weather events that cause asset and income losses will increase (see, for example, Hallegatte et al., 2016; Birkmann et al., 2022).
- ii. Agricultural incomes will, in most cases, fall (see, for example, Ortiz-Bobea et al., 2021). In most countries close to the equator, climate change will bring yield reductions with income losses for agricultural households (Bezner Kerr et al., 2022) and ambiguous impacts on food prices (see, for example, Costinot et al., 2016). In some countries (for example, in Eastern Africa and Mongolia), this will bring yield increases and income gains.
- iii. Although less well understood, droughts will also have impacts in urban areas through their impacts on health and productivity. In Latin America, droughts are estimated to have four times the impact on income losses than floods in urban areas (Damania et al., 2017).
- iv. Higher temperatures will reduce labor productivity and in the extreme increase mortality (as the risk of heat-associated deaths increases) and morbidity, as a changing climate will increase the prevalence of some pathogens (see, for example, Hsiang et al., 2019; Carleton et al., 2022).
- v. Sea level rise will make some places uninhabitable (see, for example, Oppenheimer et al., 2019). Land currently occupied by approximately a third of Bangladesh's and Vietnam's populations is projected to permanently fall below the high tide lines by 2100 (Kulp & Strauss, 2019).
- vi. Higher temperatures and rainfall shocks have been linked to more civil conflicts (see Burke, Hsiang, and Miguel [2015] and Koubi [2019] for a comprehensive review), crimes (Blakeslee & Fishman, 2018), and gender-based violence (Miguel, 2005; Sekhri & Storeygard, 2014).

## 2.4. Measuring the Welfare Impacts of Climate Change

### Damage or Vulnerability Functions

A key component of any measure of the welfare impacts of climate change is the vulnerability or damage function (these terms can be used interchangeably) that relates losses in welfare to climate conditions. This has been estimated several ways in the climate economics literature (see Auffhammer [2018] for a good review).

Analyses focusing on weather shocks can be used to examine the impact of extreme weather events on welfare, corresponding to estimate the vulnerability function described in equation (2). The method most commonly used in welfare analysis

relies on estimates derived from observed data and identifies the causal impact of weather changes on outcomes of interest by examining the effects of specific weather events in a particular location at a specific point in time. The underlying assumption is that while the probability distribution of an event may not be considered exogenous, its timing—conditional on the distribution—is assumed to be exogenous to the households. Auffhammer (2018) and Dell et al. (2014) provide an overview of the method. In summary, data on hazards are matched to household observations in survey data using the best available data on the geographic location of a household (either admin codes or GPS) and a fixed effects regression is run to identify the

impact of weather in determining welfare. Baquie & Foucault (2023), Gascoigne et al. (2024), and Strobl & Spencer (2024) provide a recent overview of methodological considerations.

While these analyses are well identified and provide information on the impacts of extreme weather events that are becoming more frequent with climate change, the response to random short-term fluctuations in weather might be very different from adaptation responses to permanent shifts and changes in average conditions. For instance, groundwater irrigation may provide a short-term adaptation strategy, but that may not be available in the long term if the resource is depleted. In addition, given few extreme events are observed, the ability to estimate the impact of truly extreme events is also limited. It is not necessarily the case that the impact of these events can be extrapolated using coefficients estimated on more moderate events.

An alternative approach is using observed trend changes to examine the impact of climate change. In these analyses, the  $c_t$  in equation (2) does not reflect a specific event but rather the change in the climate over time. The coefficient being estimated is much closer to the coefficient required to estimate the impact of climate change on welfare, but the challenge of these analyses is that it is much less plausible that the coefficient

being estimated reflects the causal impact of the changing climate on the outcome of interest. Table 1 summarizes and highlights the advantages and caveats of each approach.

The first approach, estimating the impact of hazards on welfare outcomes (income, consumption, poverty, or nutrition outcomes) for exposed people, has been a core aspect of applied microeconomic analysis, including much work by the World Bank. Dell et al. (2014) provide a review of earlier work on this and Kala et al. (2023) review some of the recent work. Recent examples of World Bank work in this area include Hill & Porter (2017), Pape & Wollburg (2019), Baez et al. (2019), Baquie & Fuje (2020), and Kochhar & Knippenberg (2023). Other work looks at how extreme weather events have impacted local economic activity. For example, Zaveri et al. (2023) use subnational GDP data and find that weather shocks reduce GDP growth by 0.4–0.8 percentage points.

Although damage/vulnerability functions have been estimated in many contexts for many years, they have not typically been used to model those at risk to climate shocks or the likely poverty impacts of future shocks or climate trends. The next section summarizes work on welfare risk from extreme weather events that are likely to become more frequent with climate change.

**Table 1:** Estimating Damage Functions

| Approach                                                                                                                           | Summary of method                                                                                                                                                                                                                                                                                                                | Data requirements                                                                                                                                                                                                                                   | Advantages                                                                                                                                                                                                                                                                                                                     | Caveats                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Examples                                                                                                                                                                             |
|------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Panel or repeated cross-sections</b> of welfare data and <b>weather shocks</b> to estimate the welfare impact of extreme events | <ol style="list-style-type: none"> <li>1. Regress welfare on measures of the weather (linearly or nonlinearly), controlling for unit-specific and time-period fixed effects</li> <li>2. To estimate differential damage impacts for different types of individuals, interact the shock with household characteristics</li> </ol> | <ol style="list-style-type: none"> <li>1. Gridded historical climate data</li> <li>2. Repeated measurements of welfare with location coordinates (can be on different individuals (cross-sectional) or the same individual (panel data))</li> </ol> | <ol style="list-style-type: none"> <li>1. Impact is causally identified (for survivors, see caveats)</li> <li>2. Can be used to understand changes in welfare over time, predict impacts of climate shocks, generate probability distributions of welfare, and simulate how welfare changes with a changing climate</li> </ol> | <ol style="list-style-type: none"> <li>1. The impact estimated is: <ul style="list-style-type: none"> <li>• <b>The direct loss</b> and not impacts beyond the local area, such as those that might arise from wider disruption of markets, macro effects</li> <li>• <b>Often a moderate shock:</b> extreme events are unlikely to be observed in the household data, limiting ability to estimate losses for extreme events</li> <li>• <b>The impact after currently available ex post and ex ante measures are used,</b> masking some of the true cost of shocks and uninsured risk</li> </ul> </li> <li>2. The estimates are also subject to survivor bias (consumption only measured for those still in place after the shock)</li> </ol> | Baez & Santos (2007); Deschênes & Greenstone (2007, 2011); Pape & Wollburg (2019); Baquie & Fuje (2020); Kochhar & Knippenberg (2023); Hill & Porter (2017); Gascoigne et al. (2024) |
| <b>Ricardian cross-sectional</b> approach to estimate the impact of a <b>changing climate</b>                                      | Regress welfare on long-term weather variables (allowing for nonlinear effects), along with control variables                                                                                                                                                                                                                    | <ol style="list-style-type: none"> <li>1. Gridded historical weather data over a substantial period of time</li> <li>2. Cross-sectional measure of welfare with location coordinates</li> </ol>                                                     | <ol style="list-style-type: none"> <li>1. Allow for private adaptation to climate conditions, based on the intuition that in a stationary climate, individuals optimize according to the environment they face and then compare outcomes in hot versus cold areas</li> <li>2. Rely on data readily available</li> </ol>        | <ol style="list-style-type: none"> <li>1. Omitted variable bias since average climate could be correlated with other unobserved time-invariant factors</li> <li>2. Assuming costless adaptation</li> <li>3. Traditional Ricardian approach only considers historical climate matters, assuming individuals base their actions on historical climate. Forward-looking Ricardian approach (Severen et al., 2018) corrects the direction and magnitude of the bias caused by failure to incorporate climate expectations into current behaviors</li> </ol>                                                                                                                                                                                      | Mendelsohn et al. (1994); Seo & Mendelsohn (2008); Dell et al. (2009); Severen et al. (2018)                                                                                         |

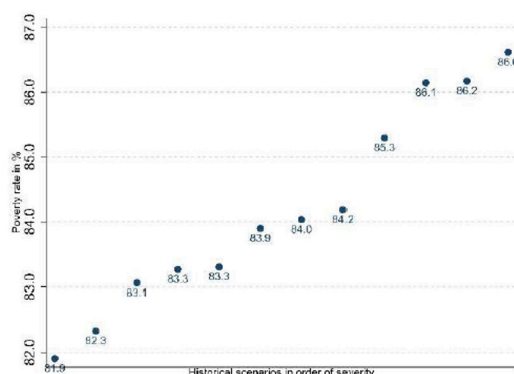
|                                                                                          |                                                                                                                                                                                                            |                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                                            |
|------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|
| <b>Long difference</b><br>estimation to estimate the impact of a <b>changing climate</b> | Construct long-term welfare and weather variables at two different points in time for a given location, then calculate changes in outcome as a function of long-term changes in average climate conditions | <ol style="list-style-type: none"> <li>1. Gridded historical weather data</li> <li>2. Panel measure of welfare with location coordinates</li> </ol> | <ol style="list-style-type: none"> <li>1. Accounting for time-invariant and time-trending unobservables, thus provide plausibly causal estimates of damages that account for observable adaptation by using differential climate trends (e.g., decadal changes)</li> <li>2. Can be used to test whether the shorter run damages of climatic variation on outcomes are in fact mitigated in the longer run</li> </ol> | <ol style="list-style-type: none"> <li>1. Omitted variable bias may remain—e.g., trends in local emissions could affect both climate and welfare outcomes</li> <li>2. Differential trends could be driven by short-run variation in weather around the chosen endpoint periods</li> <li>3. Baseline used for comparison incorporates some degree of adaptation</li> <li>4. Significant data requirements (broad spatial coverage of data over long periods of time)</li> </ol> | Dell et al. (2012); Burke & Emerick (2016) |
|------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|

Source: This table is drawn from three review articles: Dell et al. (2014), Auffhammer (2018), and Baquie & Foucault (2024).

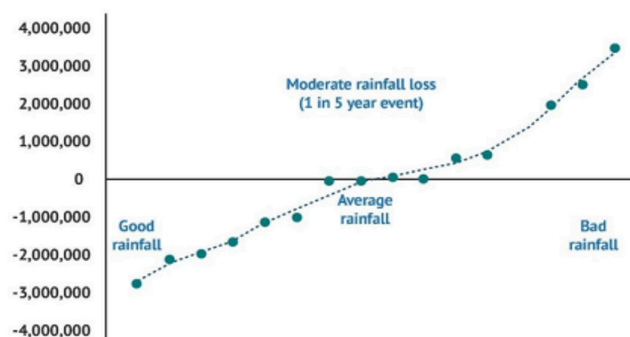
### Quantifying the Welfare Risk of Extreme Weather Events

Once a vulnerability function is estimated, it can be combined with hazard and exposure data to estimate the expected welfare loss of different climate events (equation [3]). These can be aggregated up to provide maps or national estimates of climate risk to welfare outcomes. Examples of this work are Porter & White (2016), Hill & Porter (2017), and Kochhar & Knippenberg (2023).

In looking at Malawi, Gascoigne et al. (2024) use historical data on a soil moisture index (figure 4) and simulated weather data (based on historical weather patterns). The graph shows the increase in the poverty rate that results from different weather events. Figure 5 comes from Bodewig et al. (2021), who use the Stress Testing Social Protection tool to determine the number of households that social protection support needs to reach in the event of a drought shock in Ethiopia.

**Figure 4:** Impact of Drought on Poverty Rate in Malawi

Source: Gascoigne et al., 2024.

**Figure 5:** Change in Number of Rural Pool as a Result of Rainfall in Ethiopia

Source: Bodewig et al., 2021.

Both examples use the historical distribution of shocks rather than the future distribution of shocks. Baquie & Foucault (2023) describe how this approach can be used to provide estimates of risk that take into account projected weather changes. The analysis involves two steps: (1) estimating the historical impact of weather on welfare using methods already highlighted, and (2) predicting the impact of future weather by simulating consumption distribution resulting from the forecasted distribution of weather.

It is important to note that this approach (and the mapping and proxy approach described below) focuses on the direct impacts of climate shocks, in that those exposed are those living in locations where the shock occurred. Having a clearer understanding of the degree to which indirect effects (such as impacts on food prices) are an important part of the welfare impact of these shocks is important for understanding the degree to which this partial equilibrium analysis captures the overall welfare cost of extreme events. The answer to this question may well differ by context, depending on the level of market integration.

Another concern with this approach, as discussed briefly above, is that it may fail to capture the impacts of future extreme events, particularly if the predicted intensity of these events falls outside the historical distribution. This limitation is significant in the context of climate change, where extreme events are likely to exceed historical norms in both frequency and severity. Baquie & Foucault (2023) recommend that researchers carefully review the variables and model specifications to effectively account for non-linearities in climate phenomena. It is also worth noting that these models capture vulnerability of households with the characteristics and behaviors they have today. Future adaptation measures may alter how households respond to shocks of similar magnitude to those historically observed. For example, Barreca et al. (2016) find that the adoption of residential air-conditioning in the United States led to the decline in the mortality impact of hot days by 75 percent.

This approach is data intensive but provides information on the size of need resulting from climate risk. However, this is not needed for many policy questions, such as which parts of the country

are more at risk from extreme weather events. Additionally, in the absence of data to estimate vulnerability, reasonable proxies have been used to estimate who is likely to be vulnerable, and those approaches can also be used to provide an indication of the number of people at risk even when intensive modeling work is not possible. We turn to these approaches now.

### Counting and Mapping Those at Risk

Much work has been undertaken by the World Bank, particularly in Poverty and Equity Assessments and Country Climate and Development Reports (CCDRs), to identify which places have more people at risk of being negatively impacted by an extreme weather event. This work uses variables that are expected to be correlated with the vulnerability function (for example, current welfare level or asset holdings of a household) and overlays these measures with measures of hazard and exposure to provide an indication of which parts of a country are more or less at risk.

One size does not fit all, and the indicators that are selected will likely need to be tailored to the country level to reflect the nature of the climate risks that the country is most exposed to. However, some useful points can be noted from the work done to date:

- **Hazard:** Choosing the right hazard data requires choosing the nature of the risk (for example, flood, drought), the severity of event that would be considered (for example, water depth in the case of flood, or water deficit in the case of drought), and the probability that a given location will experience such an event

(for risk modeling, this is usually expressed in return period, the expected number of years in which the event will occur once). Much can be learned from existing work on mapping hazards (see, for example, the Global Facility for Disaster Reduction and Recovery's [overview](#) of commonly used hazard data sets). There are some hazards for which choosing the data is more challenging, such as drought, but recent work suggests that the Normalized Difference Vegetation Index (NDVI) or a soil moisture index works well across settings.

- **Exposure:** Gridded population data are used for exposure when it comes to outcomes, such as welfare, which affect people. If there are shocks that some people are not exposed to—for example, drought conditions for those living in a city—then the population that is exposed (in this example, the rural population) can be used for the exposure layer. Most mapping work in the practice uses the [Global Human Settlement Layer](#) from the European Commission – Joint Research Centre).
- **Vulnerability:** The [Geospatial Poverty Portal](#) provides poverty data at the admin 1 or 2 level for most countries in the world and is a useful starting point for looking at an income dimension of vulnerability (box 1). In countries where poverty maps are available, poverty at a finer level of disaggregation can be used. In the absence of poverty map data, some teams have used the relative wealth index (Chi et al., 2022). Data on additional aspects of vulnerability, such as access to markets, finance, and social protection, which are captured in household surveys have also been used (Doan et al., 2023).

**BOX 1:** The Difference Between Measuring Vulnerability and Vulnerability to Poverty

In the hazard, exposure, and vulnerability framework, *vulnerability* is a characteristic of a person or household. In the welfare literature, *vulnerability* refers to the likelihood of being poor—a function of both the characteristics of the household and the uncertainty the households face as a result of climate and other shocks. While the “vulnerability to poverty” concept is not being used in this paper, we review in this box how the literature has measured the concept, as it is still used in welfare analysis. Many of the early estimates on measuring vulnerability to poverty used panel data that had repeated observations of welfare outcomes on the same individual. Given this type of data is often not available, there is a long tradition in the World Bank of providing an estimate of the vulnerability to poverty by using insights from available panel data work. This requires using panel data to estimate the level of consumption or income that an individual would need in order to have a low probability of falling into poverty. López-Calva & Ortiz-Juarez (2014) proposed using a 10 percent probability of becoming poor to identify those vulnerable to poverty. Using this approach, they calculated that the vulnerability threshold for Chile, Mexico, and Peru is about 2.5 times the poverty line. Similar analysis in Indonesia found that the vulnerability threshold is 1.5 times the poverty line (Jellema et al., 2017; World Bank, 2019b).

This approach—of setting a vulnerability to poverty line at some multiple of the poverty line—has been used in World Bank regional reports and poverty assessments for Brazil, Cambodia, Mongolia, Tanzania, Türkiye, Uganda, Vietnam, and others. The multiples used range from 1.25 to 2.5 times the poverty line depending on the context.<sup>a</sup> In the context of the United States, several studies have considered the threshold between 1.25 and 2 times the Federal Poverty Guidelines to identify those who are poor or near poor, including Montgomery et al. (1996), Heggeness & Hokayem (2013), Hair et al. (2015), Saczewska-Piotrowska (2016), and Dube (2019).

- a. Recent poverty assessment reports use a range of multiples of the poverty line to define vulnerability to poverty: 1.25 for Cambodia (Karamba et al., 2022), 1.5 for Indonesia and Myanmar (Pape & Ali, 2023; World Bank, 2022h), 1.7 for Vietnam (World Bank, 2022c), 1.75 for EAP (Ruggeri Laderchi et al., 2017), 2 for Brazil, Europe and Central Asia, Honduras, Peru, and Uganda (World Bank, 2022a; Bussolo et al., 2018; Robayo-Abril et al., 2023; Word Bank, 2023d; World Bank, 2016), and almost 2.5 for Latin American and the Caribbean (World Bank, 2021).

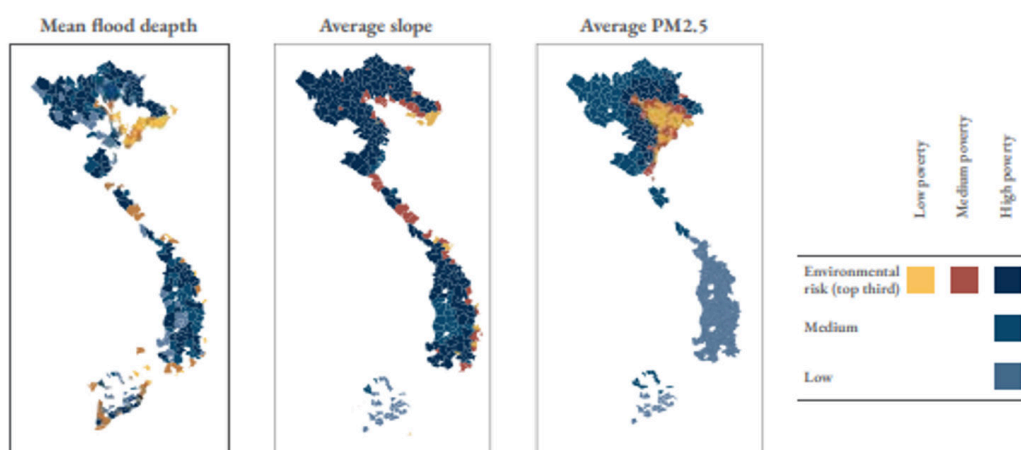
A number of reports undertaken by the World Bank have overlaid exposure and poverty. For instance, figure 6, taken from the *2022 Vietnam Poverty and Equity Assessment*, illustrates the overlap between poverty and environmental risk maps in Vietnam (World Bank, 2022c). Additional examples can be found in the Poverty and Equity Assessments of Brazil and Honduras (World Bank, 2022a; Robayo-Abril et al., 2023) and the CCDRs for Cambodia and

Pakistan (World Bank, 2023a; World Bank, 2022f). Other work explores overlaying other dimensions of vulnerability (see, for example, the Project Targeting Index work). Doan et al. (2023) provide a global estimate of the number of people at risk of extreme weather events (flood, drought, cyclone, or heat wave); these are the people who are both exposed and highly vulnerable. Vulnerability is assessed by a set of indicators capturing the physical propensity

to experience severe losses (proxied by the lack of access to basic infrastructure services) and the inability to cope with and recover from losses

(proxied by low income, not having education, not having access to financial services, and not having access to social protection).

**Figure 6:** Overlapping Maps of Vulnerability (Measured by Poverty) and Exposure to Hazards in Vietnam



Source: World Bank, 2022c.

### Modeling the Welfare Impacts of Climate Change

A body of literature on assessing the welfare impacts of climate change uses damage functions to estimate welfare losses resulting from the changing trend in climate conditions. Much of the published literature uses impacts on GDP per capita as a proxy for welfare impacts rather than modeling the distributional implications of climate change (Costinot et al., 2016; Cruz & Rossi-Hansberg, 2021). Prior to the establishment of CCDRs, few World Bank studies examined the impacts of climate change on poverty, with the notable exception of Hallegatte et al. (2016), which introduced the shock waves approach.

Two main ex ante microsimulation approaches are used in CCDRs to assess the future distributional

impact of climate change: (a) top-down approaches, consisting of the reweighting and behavioral approaches, and (b) the shock waves approach. Both approaches consist of two main steps: (i) using the latest household survey data, demographic projections, and the outcomes of macroeconomic models<sup>2</sup> to project the distribution of households and household incomes into the future, and (ii) using predictions of the impact of climate changes on incomes and prices to estimate the impact of climate change on this future income distribution. Hernani-Limarino et al. (forthcoming) review the strengths and challenges of each method and offer guidance for applications. Table 2 is taken from this review and goes into more detail on how each step is done, and the main strengths and limitations of each approach.

2. The two most commonly used macroeconomic models are a macro-fiscal model (MFMod, Burns et al., 2019) and full general equilibrium models Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) model (Van der Mensbrugghe, 2010) and Mitigation, Adaptation, and New technologies Applied General Equilibrium (MANAGE) model (Van der Mensbrugghe, 2020).

**Table 2: A Summary of Microsimulation Approaches**

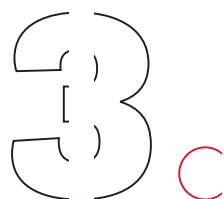
|                                          | Top-down reweighting                                                                                                                                                                                                                                                                                                                                                                                   | Top-down behavioral                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Shock waves                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Method used to establish baseline</b> | <ul style="list-style-type: none"> <li>Demographic changes (age, schooling, location) and employment status changes incorporated through changes in the population weights in the survey</li> <li>Wages adjusted through residual growth to match labor productivity growth assumption</li> <li>Nonlabor incomes adjusted to match nonlabor incomes and tax/transfers changes assumptions</li> </ul>   | <ul style="list-style-type: none"> <li>Demographic changes (age, schooling, location) incorporated through changes in the population weights in the survey. Changes in employment (and corresponding wage changes) simulated from an econometric labor supply model</li> <li>Additional wage adjustment through residual growth to match labor productivity growth assumption</li> <li>Nonlabor incomes adjusted to match nonlabor incomes and tax/transfers changes assumptions</li> </ul> | <ul style="list-style-type: none"> <li>Demographic changes (age, schooling, location) and employment status changes incorporated through changes in the population weights in the survey.</li> <li>Wages adjusted through residual growth to match labor productivity growth assumption</li> <li>Nonlabor incomes adjusted to match nonlabor incomes and tax/transfers changes assumptions</li> </ul>                                                                                                                                                                                            |
| <b>Baseline model inputs</b>             | <ul style="list-style-type: none"> <li>Use demographic forecasts from global institutions for demographic changes</li> <li>Use macro model simulation without climate change for assumptions on changes in distribution of employment status (e.g., activity, unemployment, and sector of employment), residual labor productivity growth, nonlabor income changes and tax/transfer changes</li> </ul> | <ul style="list-style-type: none"> <li>Use demographic forecasts from global institutions for demographic changes</li> <li>Use macro model without climate change for assumptions on residual labor productivity growth, nonlabor income changes and tax/transfer changes</li> </ul>                                                                                                                                                                                                        | <ul style="list-style-type: none"> <li>Use demographic forecasts from global institutions for demographic changes</li> <li>Use a sample of a combinatorial of historical trends for changes in distribution of employment status (e.g., activity, unemployment, and sector of employment), labor productivity growth, nonlabor income changes and tax/transfer changes. The sample can be created with or without correlation between assumptions. If some of these variables are available from a macro model, it is possible to use a macro model simulation without climate change</li> </ul> |
| <b>Climate change impacts</b>            | <ul style="list-style-type: none"> <li>New set of changes in distribution of employment status (e.g., activity, unemployment, and sector of employment), labor productivity growth, nonlabor income changes and tax/transfer changes provided by a macro model simulation with climate change impacts</li> </ul>                                                                                       | <ul style="list-style-type: none"> <li>New set of changes for labor productivity growth, nonlabor income changes and tax/transfer changes provided by a macro model simulation with climate change impacts</li> </ul>                                                                                                                                                                                                                                                                       | <ul style="list-style-type: none"> <li>Household specific climate shocks that reduce labor and nonlabor income depending on the household characteristics</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                             |

|                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Treatment of uncertainty</b>     | <ul style="list-style-type: none"> <li>Typically, one or two baseline scenarios versus two or more climate change scenarios</li> </ul>                                                                                                                                                                                                                                                                                              | <ul style="list-style-type: none"> <li>Typically, one or two baseline scenarios versus two or more climate change scenarios</li> </ul>                                                                                                                                                                                                                                                                                                                          | <ul style="list-style-type: none"> <li>Hundreds of baseline scenarios combined one by one with two climate impacts scenarios, or with random draws of climate scenarios taken within the two extremes</li> </ul>                                                                                                                                                                                                          |
| <b>Advantages and disadvantages</b> | <ul style="list-style-type: none"> <li>Macroeconomic consistency ensured but requires a macro model</li> <li>Limits the set of households to the ones initially present in the survey</li> <li>General equilibrium effects of climate impacts are captured</li> <li>Climate impacts are only captured if they significantly impact employment and wages at the macro level, some of the heterogeneity of impacts is lost</li> </ul> | <ul style="list-style-type: none"> <li>Macroeconomic consistency ensured but requires a macro model</li> <li>Labor market dynamics modeled, but calibrations of behavioral equations may not hold in the long run</li> <li>General equilibrium effects of climate impacts are captured</li> <li>Climate impacts are only captured if they significantly impact employment and wages at the macro level, some of the heterogeneity of impacts is lost</li> </ul> | <ul style="list-style-type: none"> <li>Macroeconomic consistency not required but can be run in the absence of a macro model</li> <li>Limits the set of households to the ones initially present in the survey</li> <li>Some—not all—general equilibrium effects of climate impacts are modeled</li> <li>Captures the heterogeneity of impacts as well as targeted impacts on small segments of the population</li> </ul> |

Source: Hernani-Limarino et al. (forthcoming).

Although there are some differences in projecting the distribution of incomes into the future, the main difference comes in how the impacts of climate change are dealt with. The top-down approaches take the outputs of a macro-model that uses damage functions to estimate the impacts of climate change on the economy. The predicted impacts on income and prices from these models are then used to predict distributional impacts. The advantage of this approach is that the impacts on households are consistent with a macro model, but the disadvantage is that much of the heterogeneity of impacts on households is lost in this approach. The shock

waves approach uses damage functions to directly estimate impacts of climate change on households. This allows for much more heterogeneity in impacts to be retained. However, the predictions are not necessarily consistent with a macro-model and not all general equilibrium impacts of climate change impacts will necessarily be taken into account. Some of the impacts will be missed as a result. The shockwaves approach also has a much stronger treatment of uncertainty, running hundreds of baseline scenarios and multiple draws of climate scenarios within two extremes.



## THE WELFARE IMPACTS OF CLIMATE POLICIES

### 3.1. The Impact of Climate Policies on Welfare

Addressing the environmental impacts of human activities requires a comprehensive understanding of their effects and the implementation of targeted policy interventions. Fossil fuel use and degradation of natural resources come with significant environmental side effects. Negative externalities occur when the actions of individuals or firms impose

costs on others that the actors do not consider. These externalities call for policy interventions to target the source of environmental harm and set the prices accordingly to reflect environmental damages while protecting the affected, vulnerable population from both climate change and the negative impacts of climate policies. Although

climate policies are often categorized based on whether they primarily contribute to mitigation or adaptation efforts, these objectives do not have to be mutually exclusive. Mitigation actions aim to reduce and/or stabilize greenhouse gas emissions, such as transitioning from fossil fuels to renewable energy or implementing carbon capture and storage or enhance natural carbon sinks through forest and land management. Adaptation or resilience building actions aim to moderate harm or seize beneficial opportunities, including preventive measures like urban greening, early warning systems, and resilient infrastructure, as well as coping mechanisms such as shock-responsive social protection or disaster management systems.

### Adapting the Hazard, Exposure, Vulnerability Framework for Welfare Analysis of Climate Action

The hazard, exposure, and vulnerability conceptual framework can be adapted to explore how policy

responses to climate change can impact welfare outcomes and generate distributional effects. Climate actions bring welfare benefits by improving the probability distribution of hazards and/or reducing exposure and vulnerability. For the purpose of the following discussion, we combine actions to reduce exposure and vulnerability into one category. Additionally, climate actions can also have welfare implications separate from the effect they have on hazards, exposure, and vulnerability. They can carry a cost (either an actual cost or a cost in terms of opportunity when money is not used for other purposes) or bring an additional benefit that directly impacts welfare. We thus add an additional channel of impact to the IPCC framework. Figure 7 summarizes this adapted framework that we use to further discuss the welfare impacts of a climate policy on an individual through three main channels: (i) hazard, (ii) exposure and vulnerability, and (iii) other benefits or costs to households.

**Figure 7:** Welfare Impacts of Climate Policy



The first channel—hazard—involves the impact of climate policies on the alteration of the probability distribution of climate, leading to a reduction or dampening of the intensity and occurrence of future climate hazards. The timing of this channel may vary depending on the policy. Mitigation measures, such as transitioning to low-carbon industrial processes and materials or implementing carbon capture and storage technologies, can stabilize the climate, but their effects are realized over an extended period (Martin et al. [2014] in the United Kingdom, Andersson [2019] in Sweden, Metcalf [2019] in British Columbia; Rafaty et al. [2021] in Europe). The IPCC *Climate Change 2023: Synthesis Report* suggests that significant and sustained reductions in emissions can result in noticeable changes in atmospheric composition within a few years and a slowdown in global warming within approximately two decades. However, policies can also bring about immediate changes in local weather conditions by modifying the natural and built environment. For example, urban trees can reduce the urban heat island effect and the risk of heat waves (Harlan et al., 2006; Ziter et al., 2019; Schwaab et al., 2021).

In the second channel—exposure and vulnerability—policies can reduce household's exposure and vulnerability to climate. Policies such as timely evacuation or planned relocations for communities in uninhabitable areas enable households to move themselves or their assets to less hazardous locations, thereby reducing their exposure (Cools et al., 2016; Miller & Dun, 2019). Policies can also reduce vulnerability by increasing the various forms of capital available to poor households, enabling them to better cope with climate shocks. For example, resilient infrastructure can reduce vulnerability to floods (Pant et al., 2018), while well-integrated markets and value chains can reduce price impacts

associated with weather shocks (Burgess & Donaldson, 2010; Baffes et al., 2015). Additionally, policies can support households in pursuing economic diversification and resilient livelihoods, reducing their reliance on income activities that are more susceptible to climate-related hazards. Higher level of education may allow households to diversify income or switch sectors when a shock occurs (Reardon, 1997; Tesfaye & Tirivayi, 2020). Public or private insurance instruments that pay out or provide transfers to households in bad weather outcomes (for example, shock-response social protection policies) also reduce vulnerability by increasing the ability of households to cope with the impacts. The strategic choice between focusing on reducing exposure or vulnerability must be informed by an assessment of whether it is exposure or vulnerability that drives the greater impact of climate on poor households' welfare. While vulnerabilities are nearly always higher for poorer households, exposure may or may not be higher for poorer households and may or may not be driving differential effects (see, for example, Banzhaf et al., 2019).

The third channel involves the costs and benefits of climate policies in relation to households' accumulation, use of, and return to assets that are *independent* of climate impacts. This policy-induced change in welfare can be positive; for example, investments in education or health can increase the returns to household's human capital by increasing their productive capacity and, subsequently, their income. It can also be negative; for example, removal of energy subsidies or the introduction of carbon pricing may reduce the net returns earned from livelihoods that use carbon (Dorband et al., 2019). In addition, given constrained public resources, financing climate action could come at the cost of reducing other welfare-enhancing investments. It is important

to consider the direct and opportunity cost of financing climate action in assessing the net welfare impact, though accurate costing of climate financing is challenging because of a lack of uniform methodologies, especially for adaptation, and standardized reporting on climate finance.<sup>3</sup>

There are three important points to note for welfare analysis:

1. Environmental externalities mean that the benefits from climate action that improves the distribution of hazards are likely to be felt by many more people than are impacted by policy-induced changes in welfare. This means that while the costs of climate action may be felt by few, the benefits will be enjoyed by many. Importantly, in the case of climate change, the externality extends across countries, and also across generations (see point 3). The fact that the externality is across countries requires a separate consideration to cross-country issues for policy making.
2. There can be considerable heterogeneity across households in the magnitude and direction of the second (exposure and vulnerability) and third (policy-induced change in welfare) channel in figure 7. This means that the overall welfare impact of a climate action can be negative for some households while positive for others. For example, the cost of switching from coal to renewable energy is higher for coal miners who lack human capital related to green skills (Hanson, 2023). Nevertheless, a comprehensive package of policies, including training programs to reskill

and upskill coal miners, can improve their welfare. Such programs not only provide an alternative to an industry that is becoming obsolete but also have the potential to increase their income (Pao-Yu et al., 2020).

3. The full beneficial impacts of climate actions on hazards are realized over the long run (Tomorrow in figure 8), whereas the costs of climate actions are more likely to be felt in the near term (Today in figure 8). However, future benefits are discounted when they are valued today and discount rates can vary across people—they are often higher for poorer people (Tanaka et al., 2010; Haushofer & Fehr, 2014)—and between citizens and policy makers (policy makers often discount the future at high rates). While a discount rate has to be chosen for policy analysis, it is important to do robustness checks for different discount rates, to see how that changes the valuation of different policies (for an example, see Clarke & Hill [2013]).

The total social welfare impact of a policy on a society will be the sum of the welfare impacts on each person across the welfare distribution, taking into account discount rates and social welfare weights. There can be trade-offs across different generations and groups of people.

---

3. For some global estimates, see World Bank and IMF (2022).

**Figure 8:** The Welfare Impacts of Climate Policy: Taking Timing Into Account

Note: Changes in a household's exposure and vulnerability are labeled simply as vulnerability for ease of exposition

We can reflect this using the equations set out in section 2. The welfare impact of climate action implemented at time  $t$  ( $Policy_t$ ) is the sum of the policy's impact on  $W_{ikt}^C$  and on the aspect of welfare that is not dependent on weather outcomes,  $W_{ikt}^{NC}$ :

$$E[W_{ikt}(Policy_t)] = E[W_{ikt}^C(Policy_t)] + W_{ikt}^{NC}(Policy_t) \quad (\text{Eq. 5})$$

This can be written as the impact of the policy on the hazard distribution, the vulnerability of a household with a given exposure, and the welfare impacts independent of climate, given by  $g(\cdot)$

$$E[W_{ikt}(Policy_t)] = \int_{\min}^{\max} h_{kt}(c_{kt}, Policy_t) f(x_{ik}(Policy_t), c_{kt}) dc + g(x_{ikt}(Policy_t)) \quad (\text{Eq. 6})$$

As noted in point 3 above, many policies impact  $h_{kt}$  only in the future. Consider a policy that only impacts the  $h_{kt}$  at time  $t+n$ , but affects household assets in the present. The discounted expected welfare impacts ( $V_{ik}$ ) of  $Policy_t$  can be written as

$$V_{ik}(Policy_t) = \int_{\min}^{\max} h_{kt}(c_{kt}) f(x_{ik}(Policy_t), c_{kt}) dc + g(x_{ikt}(Policy_t)) + \delta_i \int_{\min}^{\max} h_{k,t+n}(c_{k,t+n}, Policy_t) f(x_{ik,t+n}, c_{t+n}) dc, \quad (\text{Eq. 7})$$

where  $\delta_i$  reflects the rate at which individual  $i$  discounts the future.

While the benefits of mitigation actions are often realized in the future through the first channel, there can be both short- and medium-term costs and benefits through the second and third channels. These policies have a cost now and there is thus a trade-off between paying now (whether in monetary terms or in growth forgone) and benefiting in the future. These trade-offs can take various forms, including potential increases in energy prices and the prices of other inelastic goods (Boyce, 2018). They can also involve shifts in sectoral labor demand, requiring adjustments in the workforces and skill sets (Borissov et al., 2019; Carbone et al., 2020). Furthermore, mitigation actions may require investments in new production processes, green technologies, and infrastructure upgrades (Blanco et al., 2022). They may bring about changes in ways of living, consuming, and thinking (Adger et al., 2013). Moreover, mitigation actions can lead to changes in land-use patterns, shifts in agricultural practices, and the restoration of natural systems (Hurlbert et al., 2019). Although trade-offs are often most evident in mitigation actions, they can also arise in adaptation actions that redirect resources toward coping with disasters, potentially affecting productive uses of those resources (Antwi-Agyei et al., 2018).

### 3.2. Policies with Minimal Trade-off

Policies that bring the largest welfare gains across time should be prioritized. These may be policies with positive welfare impacts across all three channels—mitigating future hazards, reducing exposure and vulnerability, and generating income for low-income households—or policies that have large benefits through one or two of the channels with little or low costs from the other channels.

These policy choices are being made under considerable uncertainty about future states of the world. In reality,  $h_{k,t+n}(\cdot)$  is not known; instead, we have expectations over this with uncertainty around these expectations. The risk of investing in the wrong thing is very real, and policy making is being undertaken in this environment. This makes the idea of no-regrets policies particularly important. No-regrets policies bring benefits today because of contemporaneous (or near-contemporaneous) impacts on the hazard distribution, or in reducing exposure of vulnerability, or policies that bring benefits of income growth regardless of the weather. This is another reason why prioritizing triple- and double-win policies is particularly important.

#### Triple Wins for Poor People

Policies that have positive welfare impacts across all three channels for people at the bottom of the income distribution can be thought of as triple-win policies for poor people. Although few policies may be triple wins, clear sets of policies fall into this category. The IPCC *Sixth Assessment Report* focuses on adaptation and contains a useful summary of policies that reduce vulnerability while bringing improvements in the hazard distribution and income benefits (see figure SPM.4(b) in IPCC

[2022]). We highlight a few areas where policy support is likely to bring triple wins:

- **Climate-smart agricultural practices** increase agricultural productivity while sequestering carbon and reducing the vulnerability of agricultural income to extreme weather events. For example, Sahel farmers use low-cost, efficient traditional practices, such as agroforestry and rainwater harvesting techniques, to accumulate rainfall, reduce runoff, and restore soils. Rainwater harvesting and agroforestry have been shown to increase soil carbon sequestration at the estimated rates of 839 kilograms and 1,359 kilograms of carbon per hectare per year, respectively, in Africa (World Bank, 2012). In Niger, these practices were found to increase yields (Aker & Jack, 2021), which is consistent with the findings of older studies that showed that yields were 16–30 percent higher among farmers implementing these techniques in Niger and Burkina Faso (Matlon, 1985). These practices also reduce vulnerability to low rainfall, allowing yield increases in low rainfall years.<sup>4</sup>
- **Policies that protect forests and mangroves** can generate incomes for local communities while improving the climate and reducing vulnerability to weather extremes (Zaveri et al., 2023). For example, in the United States, a large-scale reforestation program in the 1930s across six Midwestern states led to enduring impacts over several decades of increased precipitation and reduced temperatures as well as increased crop yields by 11–22 percent (Grosset et al., 2023). Halting annual mangrove deforestation in Indonesia could reduce emissions by 10–31

4. For more information on the Sahel example, see Baquie & Hill (2023).

percent of estimated annual emissions from land-use sectors at present (Murdiyarso et al., 2015). Additionally, mangroves serve as barriers against cyclones, storms, and tidal surges and as a main source of income for nearby households (Das et al., 2022).

- **Improving access to clean and improved energy sources** can also bring triple wins. Over half of all wood harvested worldwide is used as fuel which contributes to black carbon and other greenhouse gas emissions but also accelerate forest degradation and deforestation (Hutton et al., 2006; Bond et al., 2013; FAO, 2023). The depletion of wood resources leads to increased time and labor burden to collect firewood for households, particularly for women. Additionally, traditional biomass stoves increase health risks associated with poor air quality, even resulting in premature deaths (Person et al., 2012). Transitioning to improved and cleaner cooking stoves thus significantly contributes to mitigating climate change, reducing exposure and vulnerability through decreased deforestation and habitat destruction, and improving household welfare by reducing health risks and pressures on women's time use.
- **Implementing energy-saving measures in buildings** not only decrease energy consumption and energy costs, thereby increasing disposable income for households, they also reduce exposure to indoor air quality pollutants as well as extreme climate events such as heat waves or cold spells (World Bank, 2019a).
- **Reducing inefficiencies in trade**, particularly in road freight transport, presents an opportunity for a triple-win policy. Trucking inefficiencies are a significant challenge, often exacerbated by regulations that limit competition and lead to

inefficient fleet management or the prevalence of empty cargos. In Central America, imperfect competition accounts for at least 35 percent of mean prices on national routes and improving cost efficiencies and increasing competition could significantly reduce freight transport prices (Osborne et al., 2014). Addressing these inefficiencies can simultaneously impact emissions positively, reduce vulnerability by better integrating markets, and promote economic growth.

This initial list of actions that offer triple wins for households at the bottom of the income distribution across various contexts needs further work to expand it. While the potential for triple wins exists across different geographical contexts and sectors, the key policy question becomes how to identify the constraints that prevent progress in these areas, and to design policies to overcome these challenges. For instance, climate-smart agricultural practices or agroforestry may require a fundamental shift in traditional techniques, necessitating new skills or knowledge that farmers may not initially possess. Training increased the adoption of soil conservation practices in the Sahel. Farmers trained on traditional soil conservation practices in the Sahel were 90 percent more likely to adopt these practices, and 50 percent more likely to have neighbors adopting the technique than untrained farmers (Aker & Jack, 2023). However, providing this type of knowledge at scale can be challenging.

Financial constraints are another common barrier, as up-front costs might be prohibitive for low-income households, and credit products are often not available, particularly for investments with long-run benefits. Addressing these constraints can significantly increase take-up. In Poland, energy-saving measures in buildings were supported through the Clean Air Priority Program, which

provided financial and operational schemes to support low-income single-family building owners in upgrading their heat sources and investing in thermo-modernization.

Even when people have enough information, training, and financial resources to access these technologies, behavioral barriers can hinder their possibility to access them—for example, the factor of risk aversion; farmers might be hesitant to adopt new practices due to uncertainty about the outcomes. Moreover, cultural and social norms can influence the willingness to adopt new methods, as practices deeply ingrained in community identity may not be easily altered.

Importantly, the existing policy environment and the incentives it provides can impede widespread take-up in these areas. Traditional agricultural support through input subsidies, output payments, or market price interventions often results in extensive environmental damage (Damanian et al., 2023). These subsidies can distort farmers' agricultural production decisions, discouraging climate-smart agricultural practices and natural resource management.<sup>5</sup> Refocusing on triple-win strategies may require a strategic shift in policy, repurposing agricultural subsidies toward climate-smart agriculture and resilient natural resource management. Existing incentives also shape the design and implementation of climate actions. For example, research by Healy & Malhotra (2009) demonstrates that voters tend to reward incumbent politicians for allocating funds to disaster relief efforts but not for investments in disaster preparedness. Recent work by Hallegatte et al. (2023) explores the political economy dimensions in more detail.

Cash transfers that support climate-smart agricultural practices and natural resource management can simultaneously address climate change, enhance resilience, and improve livelihoods. Ethiopia's flagship public works program alleviated poverty and food insecurity, bolstered community resilience against shocks (Wiseman et al., 2010), and increased tree cover through soil and water conservation and reforestation initiatives (Hirvonen et al., 2022).<sup>6</sup> In Burkina Faso, conditional environmental cash transfers raised household consumption by 12 percent and reduced severe food insecurity by 60 percent while aiming to increase the survival rate of trees planted on degraded forest lands (Adjognon & Guthoff, 2021).

There is thus an important role in identifying both the high-value triple-win opportunities and the constraints that impede progress in a given context. The type of work undertaken in the Rural Income Diagnostic tool can help in this regard. For example, in Burkina Faso the tool highlighted the opportunity of soil conservation practices for agricultural income growth for poor households and the knowledge, credit, and policy incentives that constrained the realization of this opportunity (World Bank, 2019c).

### Double Wins for Poor People

While it is useful to identify the triple wins, many policies that offer significant benefits in reducing vulnerability and improving income growth, even after accounting for their costs, have minimal impacts on the future hazard distribution. These policies are just as important to prioritize. Indeed, it is not the number of areas of positive impact

5. It is important to caution that the process of removing input subsidies may have significant impacts on households. Ghose et al. (2023) estimate that a fertilizer import ban in Sri Lanka leads to declines in crop yields by 1–14 percent across crops and welfare for both landowners and workers. While workers suffered less than landowners everywhere, workers living in heavily agricultural regions still face as much as a 3 percent income reduction.

6. Analyzing a similar public works program in Malawi, Beegle et al. (2017) find no evidence that the program improves food security and suggestive evidence of negative spillovers to untreated households.

that matter but the overall welfare benefit from each policy. In this section, we highlight some of the evidence on what these policies are. Additional review work will add to this set of examples.

For example, mobile money spurs development, thereby increasing welfare (Batista & Vicente, 2023). When a weather crisis strikes, it also allows households to quickly receive transfers or remittances quickly from relatives or migrant family members who live elsewhere (Jack & Suri, 2014). Similarly, better access to roads in remote areas increases access to markets, goods, and services, thereby bringing development. When drought reduces local food availability, improved access to markets reduces the impact of this weather shock on local food prices (Burgess & Donaldson, 2010). Education increases an individual's ability to earn income—and the gain in lifetime earnings usually more than offsets the cost of public spending (Hendren & Sprung Keyser, 2020)—but it also allows households to switch sectors when climate shocks reduce returns in the sector in which they are engaged. Furthermore, a recent study shows each additional year of education leads to increases in pro-climate beliefs, behaviors, most policy preferences, and even green voting across 16 European countries (Angrist et al., 2023). Moreover, the impact of education on voting is significant and equates to a substantial 35 percent increase. None of these policies and similar policies would be considered adaptation investments designed to reduce the vulnerability of households to climate events, but they can be highly effective in reducing vulnerability.

Without actions to reduce the carbon footprint of goods and energy consumed in a country, development policies, like many growth-enhancing

policies, can increase emissions. At low levels of growth or for very poor countries, growth in emissions may have a negligible impact on the hazard distribution in the future (Wollburg et al., 2023). The anticipated welfare impact of these policies is thus expected to be very high.

In middle-income countries, or in scenarios where growth rates are high, the increase in emissions is substantial, potentially accelerating the worsening of future hazard distributions (Wollburg et al., 2023). For example, Gertler et al. (2016) demonstrate the nonlinear relationship between income and both asset ownership and energy consumption in Mexico. Policies that promote renewable energy and increase the cost of carbon can sustain growth and alleviate poverty while reducing emissions. This approach aligns with key findings from evaluating policy packages in the Pakistan CCDR (World Bank, 2022f).

### 3.3. Addressing Trade-offs: Reducing Vulnerability at a Cost to Income Growth

In many cases, however, the cost of reducing hazard, exposure, or vulnerability is not offset by resulting income growth. There is a net cost for these actions. In this section, we consider the costs arising from reducing exposure/vulnerability (with a focus on vulnerability), and in the next section we consider the costs arising from improving the hazard distribution.

In the case of vulnerability, many of the available risk reduction and risk management strategies come with a cost for average incomes.<sup>7</sup> For example, in the case of risk reduction, agricultural practices that reduce vulnerability by reducing yield losses under weather extremes often also result in lower agricultural income in normal weather years. Kala et al. (2023) provide a review of this evidence. One notable paper is by Hultgren et al. (2022), who show that agricultural practices that adapt to rising temperatures depress yields during periods of moderate temperatures. In the case of risk management, the cost of private insurance is always higher than the actuarial fair price of insurance. The cost of publicly financing shock-responsive safety nets may or may not be recovered through the income growth enabled; there is currently not enough evidence in this area to say.

The welfare benefit to spending on reducing vulnerability comes from the fact that individuals are risk averse and thus prefer to reduce their consumption to minimize its variance, in particular the downside losses. Given there is a cost to reducing the variance in consumption, no variance in consumption is not always the optimal solution. Welfare is maximized when the variance in consumption is reduced to acceptable

levels given the cost of reducing the variance of consumption and risk preferences. Policies that increase the availability of low-cost risk reduction and management strategies need to be prioritized.

The framework set out by Ehrlich & Becker (1972) highlights the need to think about optimizing investments in risk reduction and risk management concurrently. The framework examines the interaction between market-provided insurance, self-insurance, and self-protection, defining market insurance as a contract in which an individual pays in advance to reduce losses when they occur, self-protection as actions taken to reduce the probability of loss, and self-insurance as actions taken to reduce the size of loss when it occurs. The authors note that actions that reduce the probability of loss often also reduce the size of the loss when this occurs, and this has implications for investments in both self-insurance and in the demand for market insurance. The key insight is that the availability of market insurance, if appropriately priced, need not reduce the demand for self-protection, avoiding the usual concerns with moral hazard.

While the model self-protection refers to actions undertaken by individuals, it could also be public actions that need to be taken to protect the well-being of those most at risk. Such actions include a range of risk reduction investments, which simultaneously change both the probability and the size of losses. These include efforts to green cities, climate-proof key infrastructure, increase the energy efficiency of buildings, and improve water management, as well as investments in climate-resilient agricultural practices and landscape restoration and reforestation, among others.

7. Risk reduction strategies are often called *ex ante* strategies, in that action is taken that reduces the impact of the shock prior to the shock occurring. They are also referred to as income smoothing. Risk management strategies are often called *ex post* strategies, in that they reduce the impact of the shock once it has occurred. They can also be referred to as consumption smoothing.

Self-insurance refers to a range of actions that individuals take to manage shocks to income without relying on formal risk transfer arrangements. This could be holding savings to draw on when income falls, relying on informal networks for a temporary consumption loan, or increasing income from other sources. Hill et al. (2021) and Kala et al. (2023) look at the degree to which these strategies are used by poor households and their impact.

Market insurance can be reframed as formal insurance. Market insurance refers to contracts in which there is an up-front payment to a second party that undertakes to provide income in the event of a state-contingent realization. In practice, although impactful when provided (as discussed in section 2), cost-effective insurance products are not widely present for the types of climate risks faced by poor and near-poor households in low- and middle-income countries and take-up tends to be low (see Hill et al. [2021] for a review). Some types of product do show promise (such as livestock insurance) and supporting the development of these markets may become increasingly important. However, in principle, such state-contingent payments could be financed and possibly also managed by the state—say, through adaptive social protection schemes that provide support to farm households faced with crop failure caused by drought, flood, or other extreme weather event, or support poor households if food prices rise above a threshold value because of a climate-related event, and so on.

Programs that have built-in automatic stabilizers, such as unemployment insurance or self-targeted employment guarantee schemes, automatically target those in need as a result of a climate disaster through self-selection. However, unemployment insurance covers few people in contexts where rates of self-employment or informal employment are high. When employment guarantee schemes

are in place, there is evidence that they play a protective role (Gehrke, 2019; Gelb et al., 2022; Afridi et al., 2022).

There is also considerable evidence that cash transfers help households manage shocks. However, the evidence is predominantly for the impact of regular cash transfers (see Hill et al. [2021] for a summary). Rigorous evidence on the impact of cash transfers provided in response to a disaster is much more limited, but it also shows significant long-run welfare benefits. In Fiji, an impact assessment conducted three months after a tropical cyclone found that households that received cash transfers recovered more quickly. For example, they were 8–10 percent more likely to have recovered from housing damage than non-beneficiaries (Mansur et al., 2018). Assessing the same cash transfer program, Ivaschenko et al. (2020) use a sharp regression discontinuity design to show that beneficiaries who received cash transfers recovered much more quickly than those who did not. Del Carpio & Macours (2009) and Macours et al. (2013) both use a cluster RCT to evaluate a conditional cash transfer (consisting of a transfer paid every two months) implemented by the Nicaraguan government in the aftermath of a drought. The evaluations document positive persistent impacts on height-for-age scores, cognitive and psycho-social development, and child labor (particularly for boys).

One paper rigorously examines the impact of anticipatory cash transfers—cash transfers provided before the full impacts of a disaster materialize—and similarly finds strongly positive impacts. Pople et al. (2021) exploit administrative constraints experienced during the rollout of anticipatory cash transfers in Bangladesh to compare treated households with otherwise comparable households that did not receive the cash transfer. Households receiving the transfer were less likely to go without

eating during the flood and reported higher child and adult food consumption (4 percent and 7 percent, respectively) after the flood. Asset losses and costly borrowing were lower and earning activity was higher for those receiving the transfers.

Lastly, a significant concern when policies overlook incentives is the risk of maladaptation. Responses to climate change can inadvertently create or aggravate risks through maladaptation actions. For instance, well-intentioned investments aimed at providing short-term relief may lead to costly lock-in effects. Over time, path dependence can set in and make corrective measures more difficult and costly to implement. An example of this is the construction of sea walls, which can cause coastal erosion farther down the coastline, or irrigation practices upstream that exacerbate water scarcity downstream. A comprehensive study referenced in the The IPCC Sixth Assessment Report, which analyzed over 300 climate change adaptation initiatives, discovers that approximately a third of these efforts resulted

in unintended and negative consequences (New et al., 2022). Such findings underscore the need for careful planning and implementation, as these maladaptive actions can worsen inequalities and increase vulnerabilities in affected communities. This issue is particularly critical in relation to irrigation infrastructure and commonly implemented insurance schemes, which are prone to well-documented moral hazard problems.

### 3.4. Addressing Trade-offs: Reducing Hazards While Minimizing Welfare Costs

Transitioning toward a low-carbon, climate-resilient economy, often referred to as the green transition, usually involves a trade-off between paying now and future benefits. These policies bring future climate benefits by altering the probability distribution of hazards (the first channel in figure 8's Tomorrow panel), but they have a cost now (the second and third channels in figure 8's Today panel). In addition, at a given point in time, the cost of the green transition is higher for specific people even though the future benefits are shared by all. Short-term costs, such as higher energy prices or job losses in carbon-intensive sectors, can be particularly hard for poorer people to manage. Therefore, assessing how the green transition impacts poor and vulnerable people and designing policies to reduce negative impacts are essential.

To manage the trade-off, the goal should be to pursue a “just transition” (see box 2 for a discussion of how this term has been used in the World Bank and other multilateral development banks) with a policy mix of climate mitigation policies accompanied by compensatory actions that would increase the benefits for poor people while minimizing the costs. For example, revenue from carbon taxes could be recycled not only to targeted transfers but also to productive investments in reskilling and upskilling, facilitating mobility, and reducing market frictions and credit market failures, among others. Such investments actively support poor households in transitioning rather than just compensate them for losses.

**BOX 2:** What Is Meant by a “Just Transition”?

At the 2019 UN Secretary General’s Climate Action Summit, the multilateral development banks (MDBs) collectively pledged to “support a just transition that promotes diversification and inclusion” and developed a set of high-level principles to guide MDB support for a just transition.<sup>a</sup> Among these, principle 4 emphasizes that “MDB support for a just transition seeks to mitigate negative socio-economic impacts and increase opportunities associated with the transition to a net zero economy, supporting affected workers and communities, and enhancing access to sustainable, inclusive and resilient livelihoods for all.”<sup>b</sup>

At the World Bank, the Just Transition for All Initiative primarily focuses on the shift away from coal. This initiative aims to “put people and communities at the center of the transition” and “work with stakeholders to create the plans, policies, and reforms needed to mitigate environmental impacts, support impacted people, and build a new clean energy future.”<sup>c</sup> The main emphasis is on facilitating the transition for workers and communities affected by the closure of coal mines and power plants (Calice & Demekas, 2023). However, the World Bank undertakes a wide range of work that supports countries to transition to a lower-carbon growth path, reflecting the people-centered approach outlined in the [World Bank Group Climate Change Action Plan 2021-2025](#).

- a. High level MDB statement: For publication at the UNSG Climate Action Summit, 22 September 2019. <https://www.adb.org/sites/default/files/page/41117/climate-change-finance-joint-mdb-statement-2019-09-23.pdf>.
- b. While the World Bank Group was not part of the MDB group that prepared the principles, inputs from the World Bank Group were included. See MDB Just Transition High-Level Principles (<https://www.eib.org/attachments/documents/mdb-just-transition-high-level-principles-en.pdf>).
- c. Just Transition for All: The World Bank Group’s Support to Countries Transitioning Away from Coal, Understanding Poverty, Extractive Industries, World Bank, <https://www.worldbank.org/en/topic/extractiveindustries/justtransition>.

There are two key aspects of a just transition:<sup>8</sup>

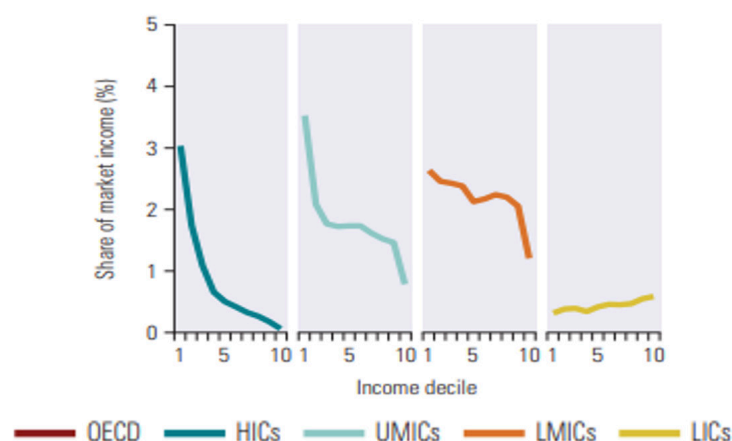
**1. Minimizing the cost to real household consumption and supporting the transition to clean energy consumption for the bottom quintiles and vulnerable groups.** Poor and vulnerable households often face higher energy prices caused by reforms aimed at reducing fossil fuel subsidies or implementing carbon taxes. Energy costs can be a large share of the budget of poor and vulnerable households, as they tend to be inefficient users of energy because of outdated appliances and poorly insulated housing. When policy reform increases energy prices, poor and vulnerable households need compensation to ensure that poverty does not

go up and deepen, as well as support to transition to more efficient appliances, better-quality housing, and cleaner transport use.

Indirect subsidies, like those for energy, are often equivalent to a higher share of market income for poorer households (World Bank, 2022h). Removing these subsidies without offering compensatory measures would disproportionately affect poor households. Figure 9 presents an incidence analysis from 94 economies, illustrating the amount that would be lost in household consumable income (shown as a share of market income) if energy subsidies were removed.

8. We focus here on welfare impacts rather than aspects related to the process of a just transition.

**Figure 9:** Subsidy Incidence Curve (Benefits as a Percentage of Market Income, by Decile)



Source: World Bank, 2022h.

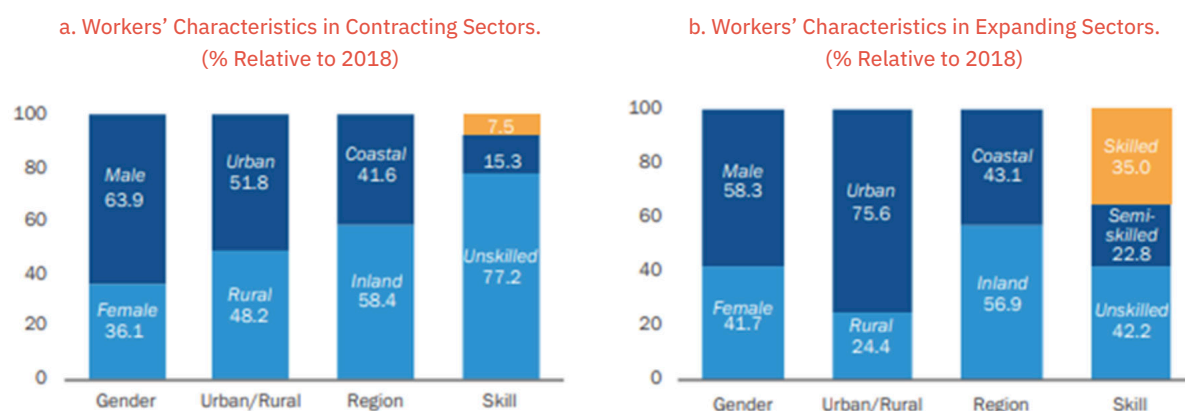
Compensatory measures, such as social assistance, can help reduce the impact on real household consumption for poor people when energy prices rise, as seen with carbon taxes or the elimination of energy subsidies. However, the current design of social protection structures is not entirely effective in protecting the poor and vulnerable from rising energy prices. The World Bank (2022h) highlights that spending on subsidies dwarfs social protection spending in lower-middle-income countries (LMICs) and low-income countries (LICs). This finding is confirmed in Mukherjee et al. (2023). A recent study by Hoy et al. (2023) shows the importance of considering other types of compensatory measures, such as investments in roads and education. They find that public support for reducing energy subsidies is low in the absence of compensatory measures but can double or even triple when such reforms are paired with compensatory policies such as investments in roads and education financed by the savings from subsidy cuts. Furthermore, in addition to compensatory policies to compensate poor households for the income effect of raising prices, complementary policies like investments in public transit or clean cooking programs will be critical

for enabling substitution toward cleaner and more efficient technologies.

## **2. Supporting the transition to low-carbon/low-methane employment and livelihoods for bottom quintiles and vulnerable groups:**

This requires support for workers, communities, and regions affected by the transition away from carbon-intensive economic activity. The improved hazard distribution is often shared across people in a given location, but the cost can be different for different people in the same location. For example, the cost of switching from coal to solar energy is larger for a person who works in a coal mine. According to the World Bank's 2022 *China CCDR*, the profile of people in sectors that contract with climate action will be very different from the profile of those in sectors that expand with climate action (figure 10). This illustrates the need for policy packages to support individuals at risk of job losses and job displacement, including compensatory transfers, insurance programs, and active labor market labor policies such as reskilling, upskilling, and job searching and matching programs.

**Figure 10:** Workers in Contracting Sectors Have a Different Profile (Low-Skilled Males Working Inland) Than Workers in Expanding Sectors (High-Skilled Males Working in Coastal Urban Areas)



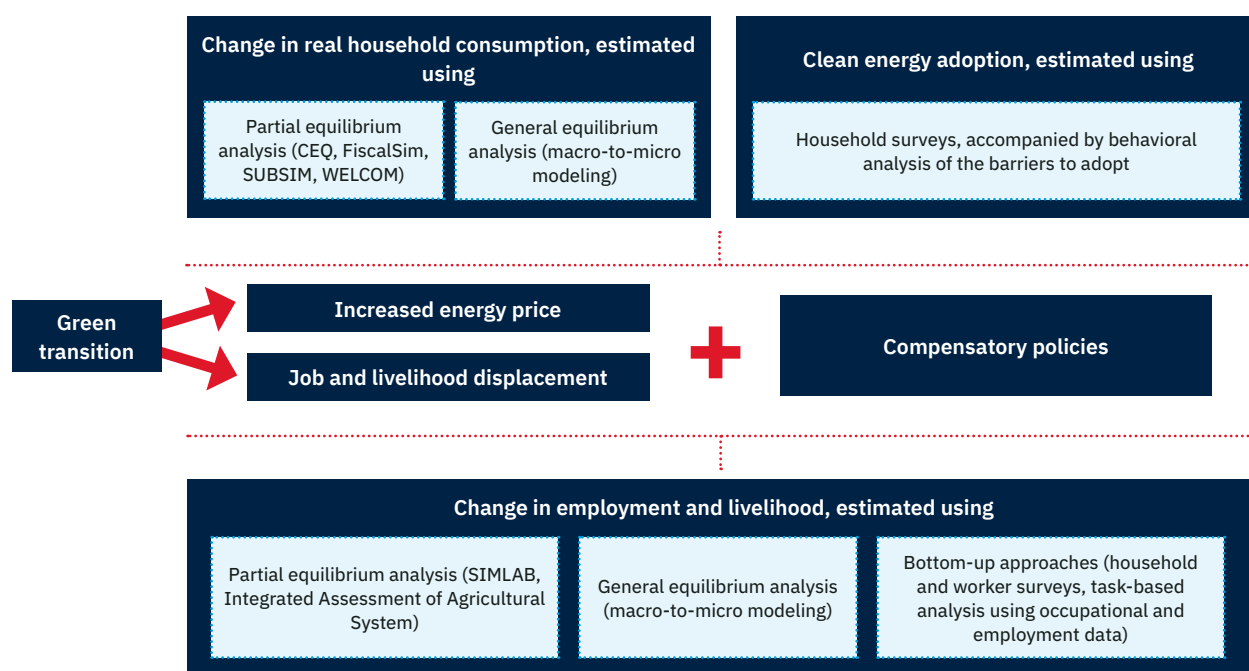
Source: World Bank, 2022b.

Note: Graphs show the distribution of jobs lost and gained, holding job characteristics fixed.

Assessing how the green transition impacts poor and vulnerable people is important for designing just transition policies. The following subsections highlight examples of recent World Bank work undertaken in this area (summarized in figure 11):

1. The impact on real household consumption
2. The adoption of clean energy consumption
3. The transition to low-carbon/low-methane employment and livelihoods

**Figure 11:** Approaches to Measure the Welfare Impact of Green Transition Policies



## Assessing the Cost of Increases in Energy Prices on Real Household Consumption

There has been substantial research assessing the distributional impacts of carbon tax and subsidy policies. Changes in households' real incomes and expenditures can be estimated using partial equilibrium analysis (including fiscal incidence and fiscal microsimulation analysis) or general equilibrium analysis (macro-micro modeling). Additionally, the Climate Policy Assessment Tool (CPAT), an Excel-based tool developed by the World Bank and the International Monetary Fund (IMF), provides a quick overview of the economic effects, including distributional effects, of carbon price intervention and subsidies.<sup>9</sup>

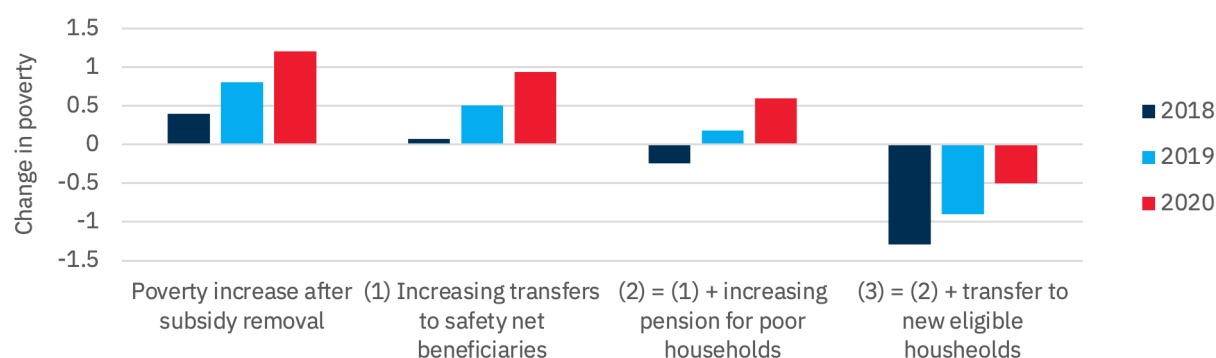
### Partial Equilibrium Analysis

Fiscal microsimulation analyses can help analyze existing policies as well as simulate alternative policy scenarios, including alternative compensation schemes and mitigation policies. The Commitment to Equity (CEQ) methodology is a diagnostic tool used to determine the distributional impact of fiscal policy by assessing the incidence and impact on poverty and inequality of each tax and social spending intervention and their combined impact. An overview of the CEQ methods and

tools is available in Lustig (2023). Based on the CEQ foundation, the World Bank has developed a customized fiscal-policy microsimulation (FiscalSim) tool to assess the distributional effects of fiscal and social spending reforms (Gao & Inchauste, 2020). FiscalSim can be used to estimate how policy reforms may affect income distribution, work incentives, and government budgets as well as the effects of changes in policies over time. The tool can also be used to compare proposed, alternative, or hypothetical policy changes, and the implications of alternative economic or demographic scenarios. Two other prepackaged simulation models are SUBsidy SIMulation (SUBSIM), which facilitates rapid distributional analyses of energy subsidies and simulations of subsidy and price reforms (Araar & Verme, 2012), and Welfare and Competition (WELCOM), which measures the distributional effects of changes in market structure induced through either regulatory reform or easing of trade barriers (Rodriguez-Castelan et al., 2019).

The above methods can be used to evaluate the size and mechanisms needed for compensatory transfers to minimize the cost faced by poor households. For example, simulations for Tunisia show that poverty increases can be compensated through a combination of additional safety net and pension transfers (Molini & Pavelesku, 2018) (figure 12).

**Figure 12:** Change in Poverty After Subsidy Removal and Compensatory Mechanism

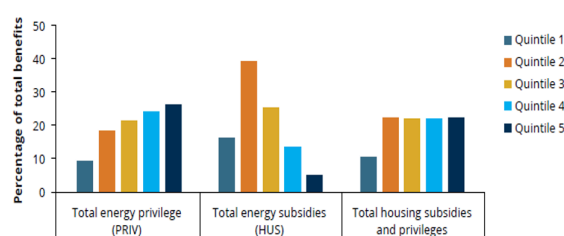


Source: Molini & Pavelesku, 2018.

9. CPAT documentation: [https://cpmodel.github.io/cpat\\_public/](https://cpmodel.github.io/cpat_public/).

A study in Ukraine shows that the poorest quintile was getting the lowest energy and housing subsidies and privileges (Olivier et al., 2023). Strikingly, only 16 percent of the energy subsidies were going to the poorest quintile (see figure 13). Simulations with alternative thresholds and norms show that this share would increase to 30 percent when the

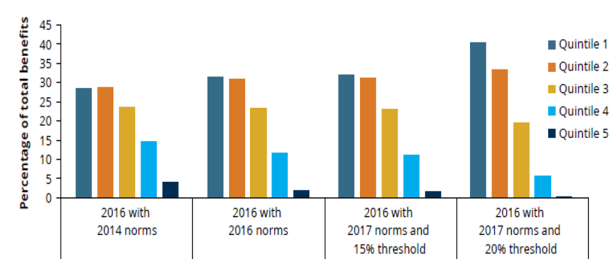
**Figure 13:** Distribution of Total Energy Subsidies (HUS) and Housing and Utility Privileges Before the Reform (2013) in Ukraine



Source: Olivier et al., 2023. Note: Data from Ukraine Household Living Conditions Survey 2013. HUS = Housing and Utility Subsidy program, PRIV = Housing and Utility Privileges program

Housing and Utility Subsidy (HUS) program was extended to most eligible households (figure 14). The actual data from the Ukraine Household Living Condition Survey 2016 show that 55 percent of the poorest quintile benefited from the HUS program in 2016, after coverage of the program grew from 8 percent in 2013 to 42 percent in 2016.

**Figure 14:** Distribution of Simulated Benefits When Extending HUS Coverage in Ukraine



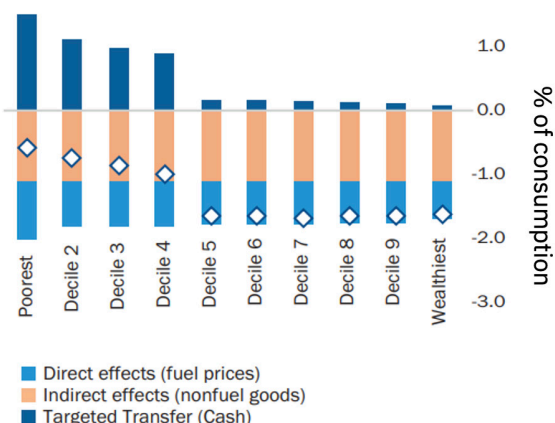
Source: Olivier et al., 2023. Note: Data from Ukraine Household Living Conditions Survey 2013. Norms are social norms for housing and utility consumption. Thresholds are the thresholds for the benefit formula.

### General Equilibrium Analysis

The top-down microsimulation approaches described in the section on “Modeling the Welfare Impacts of Climate Change” can estimate both the distribution of climate change and climate action on real household consumption. The example illustrated in figure 15 comes from the Kazakhstan CCDD, showing that phasing out fossil fuel subsidies can generate savings to the budget to offset the adverse impacts of price changes on the poor (World Bank, 2022d). The Colombia

CCDD also shows that tax reform to increase the progressivity of the tax system can create space to compensate the most vulnerable households for losses from higher carbon prices (figure 16) (World Bank, 2023b).

**Figure 15:** Potential impact of US\$20 Carbon Price with Full Redistribution to the Bottom 40 Percent: Relative Mean Consumption Effect



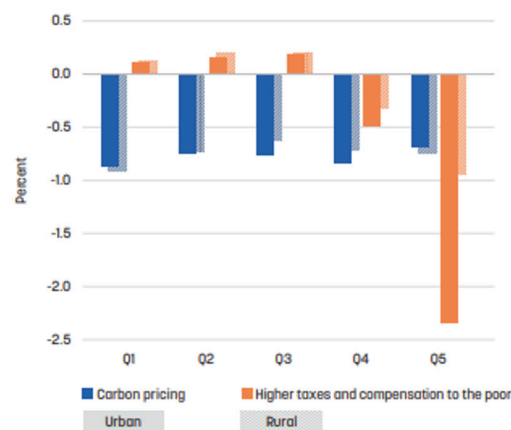
Source: World Bank, 2022d.

Note: Analysis is based on a US\$20 carbon price by 2030, 10 percent auctioning by 2030, an equivalent carbon tax on transport, 100 percent recycling of revenue, and 20 percent leakage in transfers.

### Addressing Financial and Behavioral Constraints to Adoption

Addressing the barriers faced by households, particularly low-income households, in transitioning to clean energy consumption, is also an important part of ensuring a just transition. Identifying these barriers is a first step to overcoming them, and there is an increasing literature that explores how to do this (e.g., Berkouwer & Dean 2022). Increasingly, World Bank analytical work has also focused on this. For example, distributional analysis undertaken to inform the World Bank's operational support for the Clean Air Priority Program (CAPP) in Poland shows that lower-income households are less able to afford the cost of heat source upgrades. On the basis of this analysis, the program formulated financial and operational schemes to support single-family building owners upgrading their heat sources and investing in thermo-modernization. The project uses a modeling approach to identify

**Figure 16:** Percentage Change in Household Consumption, by Quintile, Relative to a Scenario Without Comprehensive Tax Reforms



Source: World Bank, 2023b.

households in need of stove upgrades or retrofitting, which informed the program to allocate costs to households for upgrades and assess affordability after receiving support from CAPP and tax relief (World Bank, 2020).

World Bank analysis in Europe, Central Asia, and Africa increasingly shows the nonfinancial and behavioral barriers faced by households and how to support behavioral change in transitioning to clean energy consumption. A behavioral diagnostic of sustainable heating transitions in the Western Balkans emphasizes the need to design and implement programs that consider the attitudes, beliefs, and preferences of the target population toward investments in cleaner, more efficient technologies. The study finds that awareness and knowledge about available programs and initiatives significantly increase the willingness to upgrade heating systems (Karver et al., 2023). Relative to respondents with no awareness about

the existence of the programs, those aware with full knowledge and those who know someone who benefited from subsidies are 18 and 17 percentage points (respectively) more likely to want to upgrade their heating systems. Furthermore, there is heterogeneity in the respondent characteristics in the willingness to upgrade, with older respondents, single-person households, and couples around 12 percentage points less likely to be willing to upgrade heating.

Underlying biases, norms, and mental models that impede the adoption of solar home systems and clean cooking by households in Sub-Saharan Africa was similarly explored by Coony et al. (2021). Interviews with households reveal that many barriers center around perceptions of the utility of solar home systems, including their financial values, thus requiring behavior change interventions to increase the uptake.

### **Assessing the Implications of a Green Transition on Employment and Livelihoods**

As discussed, the economic risks and benefits arising from the green transition may not be uniformly distributed across worker profiles, time, and geographical locations. Consequently, there is an urgent need to assess distributional impacts on jobs and address two key questions:

1. How can vulnerable workers be supported in transitioning to a greener sector or occupation?
2. How can agricultural households and small-scale, informal enterprises be supported in transitioning to greener production?

Attributing employment and livelihood impact to the green transition is challenging because it is difficult to identify who is impacted, whether

directly, indirectly, or through induced effects. In the context where rich data are available, such as the United States, researchers can possibly explore these questions in great details. For example, Hanson (2023) shows the spatial distribution of employment in fossil-fuel-intensive activities across the United States from 2000 forward and then examines how policy options address the consequences of job loss caused by the decline in coal mining since 1980. However, more often than not, data availability is more constrained in the LIC and LMIC context, and even with a narrow focus, tracking workers, households, or firms directly impacted by the green transition requires panel surveys. For example, understanding the impacts on employment requires detailed surveys with information on whether displaced workers remain unemployed—with or without compensation—or whether they manage to secure greener jobs with comparable wages. Furthermore, the impacts of some green policies, such as a carbon border-adjustment tax or levies on non-green technologies, are mostly indirect. Despite these challenges, it is important to proactively address the essential data and methodologies required for monitoring the progress of a just transition, with a specific focus on the employment and livelihood dimension.<sup>10</sup>

This section reviews recent efforts undertaken by the World Bank and others to understand the employment and livelihood impacts of the green transition in developing country contexts. Examples of emerging approaches include: (i) measuring current green versus brown jobs and who hold these jobs, (ii) modeling possible shifts in labor demand, who may be affected, and impacts of complementary policies (iii) assessing the possibility to move jobs given shifting demands, and (iv) assessing the impacts of coal region transition specifically.

---

10. For an overview of studies that analyze the impacts of green policies on jobs, see Bowen & Kuralbayeva (2015) and Van der Ree (2019).

First, measuring green versus brown jobs and the profile of workers in those jobs can yield insights into who may be affected by the green transition. A new strand of work leverages detailed occupation information to determine the extent of an occupation's "greenness." Doan & Nguyen (forthcoming) briefly review measuring green skills. This approach considers a spectrum of greenness, thus allowing for jobs to be identified as directly or indirectly green. The most dominant bottom-up approach is task-based analysis, which categorizes occupations based on the overall greenness of their task content. Vona et al. (2018) pioneered this approach by leveraging comprehensive data sets from the US Occupational Information Network (O\*NET) taxonomy and granular employment data from the Bureau of Labor Statistics to identify jobs more susceptible to green transitions and explore associated skills requirements in the United States. Researchers have extended the O\*NET taxonomy to the occupational classification systems of other economies based on the assumption that these countries share the same set of green tasks (Valero et al., 2021; IMF, 2022; OECD, 2023; Di Maro et al., forthcoming). The World Bank has recently supported three initiatives in improving country-specific occupational classification in Indonesia, Uruguay, and Vietnam.

Second, to assess possible labor market impacts, a general equilibrium approach combined with macro-to-micro modeling can be used to study the impacts on employment, similar to the example of the China CCDR (figure 13). The Model of Innovation in Dynamic Low-Carbon Structural Economic and Employment Transformations (MINDSET) macro-to-micro model can also assess possible shifts in labor demand, who may be affected, and the impacts of select complementary policies.<sup>11</sup> Alternatively, the International Labour Organization (ILO) has established the Green Jobs Assessment Institution Network (GAIN) and developed the

Green Jobs Assessment Model (GJAM), which uses a dynamic-recursive model combining macroeconomic equations with a supply-and-use table (SUT) system. Several published reports using GJAM included low- and middle-income countries. The ILO's training guidebook reviews methods of documenting green jobs and provides assessment tools, including recommended surveys on employment in the environmental sector and green jobs (ILO, 2017).

Regarding labor market policies, a tool like Simulation of Labor Economics (SIMLAB), while originally not intended to look at climate, shows the potential to explore the trade-offs associated with specific climate policies and the impacts of complementary actions. SIMLAB is a structural macro-micro simulation tool designed to analyze the distributional impacts of human capital policies on the labor market and poverty. For a comprehensive review, refer to Robayo-Abril (forthcoming). This tool facilitates ex ante analysis of selected labor policy reforms, including human capital policies, public sector employment policies, formalization, and labor market policies.

In the agrifood sector, Nico & Christiaensen (2023) analyze the implications of the green transition on jobs by merging the results from existing, integrated agricultural assessment models with insights from structural transformation and leveraging econometric estimates to provide a comprehensive view.

Third, to assess the possibility to move jobs given shifting demands, a complementary method is the occupational mobility network analysis, which visualizes the clustering and segregation patterns in occupational mobility and task similarity as economies transition to greener sectors and industries (Mealy, 2022). Since the economic benefits and risks of the green transition may not be uniformly distributed across worker profiles, time, and geographical locations, this method helps

11. MINDSET is a post-Keynesian single-year model developed by the World Bank that focuses on the demand side and assumes that the economy is always operating below full capacity, meaning that more resources (such as labor) may be brought into production when needed. It is previously named Multiregional input-output (MRIO) model. Additional details on the modeling approach are in World Bank (2023a).

inform the required skills, job quality, and locations of jobs that might be affected by green policies and the green transition.

Fourth, assessing employment impacts is critical to supporting a just coal region transition. Recent studies from the Lower Silesia, Silesia, and Wielkopolska regions in Poland have introduced several innovative methods to study the employment impacts of the coal transition (Christiaensen, Ferré, Gajderowicz, & Wrona, 2022; Christiaensen, Ferré, Gajderowicz, Ruppert Bulmer, et al., 2022; Christiaensen, Ferré, Honorati, et al., 2022). These methods include employing a novel bottom-up approach to calculate the number of workers indirectly affected by coal mine closures (defined as positions in associated subsidiaries or subcontractors with the mining conglomerates), utilizing discrete choice experiments to gauge the preferences of workers impacted by these closures

regarding job attributes, and implementing a new artificial intelligence-powered job matching tool designed to identify optimal alternative employment opportunities for affected individuals (similar idea to Mealy [2022]). Closely related to the last method, online job postings have increasingly become a powerful source of data for researchers. Lassébie et al. (2021) apply machine learning to classify skill requirements in online job postings in several Organisation for Economic Co-operation and Development (OECD) countries into broader skill categories and validate against the O\*NET information on skills by occupations. A few other papers apply natural language processing and expert survey to online job vacancy data to gain job-level perspectives in the United States (Saussay et al., 2022; Curtis et al., 2023).

### 3.5. Cross-Border Issues and Climate Justice

This framework has focused on country-level welfare analysis. However, given that climatic shocks can transcend national boundaries, and that climate change is a global externality, policies in one economy can impact the probability distribution of hazards in another. Thus, cross-border issues are important to consider, even in country welfare analysis. In this section, we set out some of the recent work in this area to provide some context and then discuss what this means for country-level analysis.

Overconsumption of carbon in high-income countries has adversely altered the probability distribution of hazards in LICs and middle-income countries (MICs), causing the problem the world collectively faces today. *The Climate Inequality*

*Report 2023* shows that about 75 percent of total historical emissions since 1850 can be attributed to North America, Europe, and China alone, with North America and Europe together accounting for nearly half of this total (Chancel et al., 2023). This, combined with the fact that the largest losses are in the world's poorest countries, means that the poorest 50 percent of the world's population faces 75 percent of the relative losses caused by climate-related events despite contributing only 12 percent of emissions. In contrast, the world's richest 10 percent are responsible for a massive 48 percent of emissions.

Two types of country-level analysis can be useful in providing more nuance to this story. First, estimating energy growth that comes from income

growth (see, for example, Gertler et al. [2016]), and second, showing that energy consumption within countries is also unequal and as a result the richest share of the population in some MICs consume more energy per capita than households in high-income countries.

Even noting this nuance, policies in high- and upper-middle-income countries, paid for by the people in those countries, have the potential to bring benefits for poor people living in LICs and LMICs. If these wealthier nations were to implement policies to reduce current emissions, there would be a significant impact on global emissions with benefits for the future global hazard distribution. In contrast, policies that reduce emissions in LICs and LMICs will have less of an impact on the hazard distribution as a result of changing the trajectory of climate change, even though they may bring local environmental benefits such as improved air and water quality and lower temperatures. Kanbur (2023) makes the point that documenting the global benefit of mitigation policies undertaken by individual countries can help underscore the contribution they are making to a global good. He argues that given the historically low contribution of LICs and LMICs to the global climate crisis, this contribution to the global benefit merits financial compensation. The first step in this discussion is documenting the global benefit from domestic policy choices.

Climate change is a global challenge that requires urgent, equitable global actions. While this entails a complex interplay of trade-offs and policy packages, thoughtful design and implementation of global climate interventions could help rectify the disproportionate burden shouldered by LMICs, contributing to a more equitable and effective global response to climate change.

## References

---

- Adger, W. N., Barnett, J., Brown, K., & Marshall, N. (2013). Cultural dimensions of climate change impacts and adaptation. *Nature Climate Change*, 3(2), 112–117.
- Adjognon, G. S., & Guthoff, J. (2021). Reducing hunger with payments for environmental services (PES): Experimental evidence from Burkina Faso. *American Journal of Agricultural Economics*, 103(3), 831–857.
- Afridi, F., Mahajan, K., & Sangwan, N. (2022). Employment guaranteed? Social protection during a pandemic. *Oxford Open Economics*, 1.
- Aker, J. C., & Jack, B. K. (2023). Harvesting the rain: The adoption of environmental technologies in the Sahel. *Review of Economics and Statistics*, 1–52.
- Alderman, H., Hoddinott, J., & Kinsey, B. (2006). Long term consequences of early childhood malnutrition. *Oxford Economic Papers*, 58(3), 450–474.
- Andersson, J. J. (2019). Carbon taxes and CO2 emissions: Sweden as a case study. *American Economic Journal: Economic Policy*, 11(4), 1–30.
- Angrist, N., Winseck, K., Patrinos, H. A., & Zivin, J. S. G. (2023). *Human capital and climate change* (Working Paper No. 31000). National Bureau of Economic Research.
- Anik, A. R., Ranjan, R., & Ranganathan, T. (2018). Estimating the impact of salinity stress on livelihood choices and incomes in rural Bangladesh. *Journal of International Development*, 30(8), 1414–1438.
- Antwi-Agyei, P., Dougill, A. J., Stringer, L. C., & Codjoe, S. N. A. (2018). Adaptation opportunities and maladaptive outcomes in climate vulnerability hotspots of northern Ghana. *Climate Risk Management*, 19, 83–93.
- Araar, A., & Verme, P. (2012). *Reforming subsidies: A toolkit for policy simulations* (Policy Research Working Paper No. 6148). World Bank.
- Artuc, E., Porto, G., & Rijkers, B. (2023). *Crops, conflict, and climate change* [Working paper].
- Auffhammer, M. (2018). Quantifying economic damages from climate change. *Journal of Economic Perspectives*, 32(4), 33–52.
- Baez, J. E., Caruso, G., & Niu, C. (2017). *Tracing back the weather origins of human welfare: Evidence from Mozambique* (Policy Research Working Paper No. 8167). World Bank Group.
- Baez, J. E., Kshirsagar, V., & Skoufias, E. (2019). *Adaptive safety nets for rural Africa: Drought-sensitive targeting with sparse data* (Policy Research Working Paper No. 9071). World Bank Group.
- Baez, J. E., & Santos, I. V. (April, 2007). Children's vulnerability to weather shocks: A natural disaster as a natural experiment. *Social science research network*, New York, 1–28.
- Baffes, J., Kshirsagar, V., & Mitchell, D. (2015). *What drives local food prices? Evidence from the Tanzanian maize market* (Policy Research Working Paper No. 7338). World Bank.
- Baquie, S., & Fuje, H. (2020). *Vulnerability to poverty following extreme weather events in Malawi* (Policy Research Working Paper No. 9435). World Bank Group.

- Baquie, S., & Hill, R. (2023). *Real-world policies for a low-carbon future (improving water availability and restoring soil fertility in the Sahel)*. World Bank.
- Baquie, S., & Foucault, G. (2023). *Background note on bringing climate change into vulnerability analysis*. Equitable Growth, Finance, & Institutions Insight. World Bank.
- Barreca, A., Clay, K., Deschenes, O., Greenstone, M. & Shapiro, J.S. (2016). Adapting to climate change: The remarkable decline in the US temperature-mortality relationship over the twentieth century. *Journal of Political Economy*, 124(1), 105-159.
- Barrett, C. B. (2021). Overcoming global food security challenges through science and solidarity. *American Journal of Agricultural Economics*, 103(2), 422–447.
- Barrett, C. B., Ortiz-Bobea, A., & Pham, T. (2023). Structural transformation, agriculture, climate, and the environment. *Review of Environmental Economics and Policy*, 17(2).
- Batista, C., & Vicente, P. C. (2023). Is mobile money changing rural Africa? Evidence from a field experiment. *Review of Economics and Statistics*, 1–29.
- Beegle, K., Galasso, E., & Goldberg, J. (2017, September). Direct and indirect effects of Malawi's public works program on food security. *Journal of Development Economics*, 128, 1–23.
- Banzhaf, S., Ma, L., & Timmins, T. (2019). Environmental justice: The economics of race, place, and pollution. *Journal of Economic Perspectives*, 33(1), 185–208.
- Berkouwer, S. B., & Dean, J. T. (2022). Credit, attention, and externalities in the adoption of energy efficient technologies by low-income households. *American Economic Review*, 112(10), 3291-3330.
- Bezner Kerr, R., Hasegawa, T., Lasco, R., Bhatt, I., Deryng, D., Farrell, A., Gurney-Smith, H., Ju, H., Lluch-Cota, S., Meza, F., Nelson, G., Neufeldt, H., & Thornton, P. (2022). Food, fibre, and other ecosystem products. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegria, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate change 2022: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 713–906. Cambridge University Press.
- Birkmann, J., Liwenga, E., Pandey R., Boyd, E., Djalante, R., Gemenne, F., Leal Filho, W., Pinho, P. F., Stringer, L., & Wrathall, D. (2022). Poverty, livelihoods, and sustainable development. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegria, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate change 2022: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 1171–1274. Cambridge University Press.
- Blakeslee, D. S., & Fishman, R. (2018). Weather shocks, agriculture, and crime: Evidence from India. *Journal of Human Resources*, 53(3), 750–782.
- Blanco, G., de Coninck, H., Agbemabiese, L., Diagne, E. H. M., Diaz Anadon, L., Lim, Y. S., Pengue, W. A., Sagar, A. D., Sugiyama, T., Tanaka, K., Verdolini, E., & Witajewski-Baltviks, J. (2022). Innovation, technology development and transfer. In P. R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, & J. Malley (Eds.), *Climate change 2022: Mitigation of climate change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 1641–1726. Cambridge University Press.

- Bodewig, C., Calcutt, E., Conner, G., Cook, S., Gentilini, U., Hill, R., Majoka, Z., Narayan, A., Saidi, M., & Tassot, C. (2021). Stress testing social protection: A rapid appraisal of the adaptability of social protection systems and their readiness to scale-up. A guide for practitioners. World Bank Group.
- Bond, T. C., Doherty, S. J., Fahey, D. W., Forster, P. M., Berntsen, T., DeAngelo, B. J., Flanner, M. G., Ghan, S., Kärcher, B., Koch, D., Kinne, S., Kondo, Y., Quinn, P. K., Sarofim, M. C., Schultz, M. G., Schulz, M., Venkataraman, C., Zhang, H., Zhang, S., ... Zender, C. S. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. *Journal of Geophysical Research: Atmospheres*, 118(11), 5380–5552.
- Borissov, K., Brausmann, A., & Bretschger, L. (2019, September). Carbon pricing, technology transition, and skill-based development. *European Economic Review*, 118, 252–269.
- Boyce, J. K. (2018, August). Carbon pricing: Effectiveness and equity. *Ecological Economics*, 150, 52–61.
- Bowen, A., & Kuralbayeva, K. (2015). Looking for green jobs: the impact of green growth on employment. Grantham Research Institute Working Policy Report. London: London School of Economics and Political Science, 1-28.
- Brunckhorst, B., Hill, R., Mansuri, G., Nguyen, T., & Doan, M. 2023. Climate and Equity: A Framework to Guide Policy Action. Poverty and Equity Global Practice. World Bank.
- Bulte, E., Cecchi, F., Lensink, R., Marr, A., & Van Asseldonk, M. (2020, December). Does bundling crop insurance with certified seeds crowd-in investments? Experimental evidence from Kenya. *Journal of Economic Behavior & Organization*, 180, 744–757.
- Bundervoet, T., Verwimp, P., & Akresh, R. (2009). Health and civil war in rural Burundi. *The Journal of Human Resources*, 44(2), 536–563.
- Burgess, R., & Donaldson, D. (2010). Can openness mitigate the effects of weather shocks? Evidence from India's famine era. *The American Economic Review*, 100(2), 449–453.
- Burke, M., & Emerick, K. (2016). Adaptation to climate change: Evidence from US agriculture. *American Economic Journal: Economic Policy*, 8(3), 106–140.
- Burke, M., Gong, E., & Jones, K. (2015). Income shocks and HIV in Africa. *The Economic Journal*, 125(585), 1157–1189.
- Burke, M., Hsiang, S. M., & Miguel, E. (2015). Climate and conflict. *Annual Review of Economics*, 7(1), 577–617.
- Burns, A., Campagne, B. P. M., Jooste, C., Stephan, D. A., & Bui, T. T. (2019). *The World Bank macro-fiscal model technical description* (Policy Research Working Paper No. 8965). World Bank.
- Bussolo, M., Davalos, M. E., Peragine, V., & Sundaram, R. (2018). *Toward a new social contract: Taking on distributional tensions in Europe and Central Asia*. Europe and Central Asia Studies. World Bank.
- Cai, H., Chen, Y., Fang, H., & Zhou, L. A. (2015). The effect of microinsurance on economic activities: Evidence from a randomized field experiment. *Review of Economics and Statistics*, 97(2), 287–300.
- Cai, J. (2016). The impact of insurance provision on household production and financial decisions. *American Economic Journal: Economic Policy*, 8(2), 44–88.
- Calice, P., & Demekas, D. G. (2023). *Mobilizing finance for the just energy transition in the European Union*. Equitable Growth, Finance, & Institutions Insight. World Bank.

- Carbone, J. C., Rivers, N., Yamazaki, A., & Yonezawa, H. (2020). Comparing applied general equilibrium and econometric estimates of the effect of an environmental policy shock. *Journal of the Association of Environmental and Resource Economists*, 7(4).
- Carleton, T., Jina, A., Delgado, M., Greenstone, M., Houser, T., Hsiang, S., Hultgren, A., Kopp, R. E., McCusker, K. E., Nath, I., Rising, J., Rode, A., Seo, H. K., Viaene, A., Yuan, J., & Zhang, A. T. (2022). Valuing the global mortality consequences of climate change accounting for adaptation costs and benefits. *The Quarterly Journal of Economics*, 137(4), 2037–2105.
- Carter, M. R., Little, P. D., Mogues, T., & Negatu, W. (2007). Poverty traps and natural disasters in Ethiopia and Honduras. *World Development*, 35(5), 835–856.
- Chancel, L., Bothe, P., & Voituriez, T. (2023). *Climate inequality report 2023: Fair taxes for a sustainable future in the Global South*. World Inequality Lab.
- Chi, G., Fang, H., Chatterjee, S., & Blumenstock, J. E. (2022). Microestimates of wealth for all low- and middle-income countries. *Proceedings of the National Academy of Sciences*, 119(3), Article e2113658119.
- Christiaensen, L., Ferré, C., Gajderowicz, T., & Wrona, S. (2022). *Towards a just coal transition: Labor market challenges and people's perspectives from Lower Silesia* (Jobs Working Paper No. 69). World Bank.
- Christiaensen, L., Ferré, C., Gajderowicz, T., Ruppert Bulmer, E., & Wrona, S. (2022). *Towards a just coal transition: Labor market challenges and people's perspectives from Silesia* (Jobs Working Paper No. 70). World Bank.
- Christiaensen, L., Ferré, C., Honorati, M., Gajderowicz, T., & Wrona, S. (2022). *Towards a just coal transition: Labor market challenges and people's perspectives from Wielkopolska* (Jobs Working Paper). World Bank.
- Clarke, D., & Hill, R. V. (2013). *Cost-benefit analysis of the African Risk Capacity facility* (IFPRI Discussion Paper 1292). International Food Policy Research Institute.
- Coony, J., Lourenco, J. S., & de Martino, S. (2021, June 10). Shining a light on misconceptions about solar home systems. *Development and a Changing Climate*.
- Cools, J., Innocenti, D., & O'Brien, S. (2016, April). Lessons from flood early warning systems. *Environmental Science & Policy*, 58, 117–122.
- Costinot, A., Donaldson, D., & Smith, C. (2016). Evolving comparative advantage and the impact of climate change in agricultural markets: Evidence from 1.7 million fields around the world. *Journal of Political Economy*, 124(1), 205–248.
- Cruz, J. L., & Rossi-Hansberg, E. (2021). *The economic geography of global warming* (Working Paper No. 28466). National Bureau of Economic Research.
- Curtis, E., O'Kane, L., & Park, R. J. (2023). *Workers and the green-energy transition: Evidence from 300 million job transitions* (Working Paper No. 31539). National Bureau of Economic Research.
- Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A., & Hansen, M. C. (2018). Classifying drivers of global forest loss. *Science*, 361(6407), 1108–1111.
- Damania, R., Desbureaux, S., Hyland, M., Islam, A., Moore, S., Rodella, A., Russ, J., & Zaveri, E. (2017). *Uncharted waters: The new economics of water scarcity and variability*. World Bank

- Damania, R., Balseca, E., De Fontaubert, C., Gill, J., Rentschler, J., Russ, J., & Zaveri, E. (2023). *Detox development: Repurposing environmentally harmful subsidies*. World Bank.
- Das, S. C., Das, S., & Tah, J. (2022). Mangrove forests and people's livelihoods. In S. C. Das Pullaiah, & E. C. Ashton (Eds.), *Mangroves: Biodiversity, livelihoods and conservation*, pp. 153–173. Springer.
- Deaton, A. S. (1997). *The analysis of household surveys: A microeconomic approach to development policy*. World Bank Group.
- Del Carpio, X. V., & Macours, K. (2009). Leveling the intra-household playing field: compensation and specialization in child labor allocation. *World Bank Policy Research Working Paper*, (4822).
- Dell, M., Jones, B. F., & Olken, B. A. (2009). Temperature and income: Reconciling new cross-sectional and panel estimates. *The American Economic Review*, 99(2), 198–204.
- Dell, M., Jones, B. F., & Olken, B. A. (2012). Temperature shocks and economic growth: Evidence from the last half century. *American Economic Journal: Macroeconomics*, 4(3), 66–95.
- Dell, M., Jones, B. F., & Olken, B. A. (2014). What do we learn from the weather? The new climate-economy literature. *Journal of Economic Literature*, 52(3), 740–798.
- Dercon, S. (2004). Growth and shocks: Evidence from rural Ethiopia. *Journal of Development Economics*, 74(2), 309–329.
- Deschênes, O., & Greenstone, M. (2007). The economic impacts of climate change: Evidence from agricultural output and random fluctuations in weather. *The American Economic Review*, 97(1), 354–385.
- Deschênes, O., & Greenstone, M. (2011). Climate change, mortality, and adaptation: Evidence from annual fluctuations in weather in the US. *American Economic Journal: Applied Economics*, 3(4), 152–185.
- Di Maro, V., Montoya, K., Olivieri, S., Vazquez, E., Winkler, H. (Forthcoming). *Green Jobs, Dirty Sectors, and the Implications for a Just Transition: Evidence from Cross-Country Comparisons with a Particular Focus on Latin America and Caribbean Countries*. World Bank.
- Doan, M. K., Hill, R., Hallegatte, S., Corral Rodas, P. A., Brunckhorst, B. J., Nguyen, M., Freije-Rodriguez, S., & Naikal, E. G. (2023). *Counting people exposed to, vulnerable to, or at high risk from climate shocks—A methodology* (Policy Research Working Paper No. 10619). World Bank Group.
- Doan, M. K., & Nguyen, T. (Forthcoming). *Literature review on quantifying green jobs*. World Bank Group.
- Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., & Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience*, 4(5), 293–297.
- Dorband, I. I., Jakob, M., Kalkuhl, M., & Steckel, J. C. (2019, March). Poverty and distributional effects of carbon pricing in low- and middle-income countries—A global comparative analysis. *World Development*, 115, 246–257.
- Dube, A. (2019). Minimum wages and the distribution of family incomes. *American Economic Journal: Applied Economics*, 11(4), 268–304.
- Eberenz, S., Lüthi, S., & Bresch, D. N. (2021). Regional tropical cyclone impact functions for globally consistent risk assessments. *Natural Hazards and Earth System Sciences*, 21(1), 393–415.
- Ehrlich, I., & Becker, G. S. (1972). Market insurance, self-insurance, and self-protection. *Journal of political Economy*, 80(4), 623–648.

- Elabed, G., & Carter, M. (2014). *Ex-ante impacts of agricultural insurance: Evidence from a field experiment in Mali* [Unpublished manuscript].
- Elbers, C., Gunning, J. W., & Kinsey, B. (2007). Growth and risk: Methodology and micro evidence. *The World Bank Economic Review*, 1.
- eMBeD. (Forthcoming). *Behavioral approaches to address climate change* [eMBeD brief]. World Bank.
- Fafchamps, M., Udry, C., & Czukas, K. (1998). Drought and saving in West Africa: Are livestock a buffer stock? *Journal of Development Economics*, 55(2), 273–305.
- FAO. (2023). *Sustainability by numbers—Forest products at FAO*. Food and Agriculture Organization.
- Fuchs, A., & Wolff, H. (2016). *Drought and retribution: Evidence from a large-scale rainfall-indexed insurance program in Mexico* (Policy Research Working Paper No. 7565). World Bank.
- Gao, J., & Inchauste, G. (2020). *A customizable microsimulation tool to analyze distributional effects of country fiscal policies* (Poverty and Equity Note No. 37). World Bank.
- Gascoigne, J., Baquie, S., Vinha, K., Skoufias, E., Calcutt, E., Kshirsagar, V., Meenan, C., & Hill, R. (2024). *The welfare cost of drought in Sub-Saharan Africa*. World Bank.
- Gehrke, E. (2019). An employment guarantee as risk insurance? Assessing the effects of the NREGS on agricultural production decisions. *The World Bank Economic Review*, 33(2), 413–435.
- Gelb, A., Giri, A., Mukherjee, A., Rautela, R., Thapliyal, M., & Webster, B. (2022). Beyond India's Lockdown: PMGKY Benefits During the COVID-19 Crisis and the State of Digital Payments. *Policy Paper*, 257.
- Gertler, P. J., Shelef, O., Wolfram, C. D., & Fuchs, A. (2016). The demand for energy-using assets among the world's rising middle classes. *The American Economic Review*, 106(6), 1366–1401.
- Gijsman, R., Horstman, E. M., Friess, D. A., Swales, A., & Wijnberg, K. M. (2021, July 8). Nature-based engineering: A review on reducing coastal flood risk with mangroves. *Frontiers in Marine Science*, 8.
- Ghose, D., Fraga, E., & Fernandes, A. (2023). *Fertilizer import bans, agricultural exports, and welfare: Evidence from Sri Lanka* (Policy Research Working Paper No. 10642). World Bank Group.
- Grosset, F., Papp, A., & Taylor, C. (2023, January 26). Rain follows the forest: Land use policy, climate change, and adaptation. *Climate Change, and Adaptation*.
- Gunnsteinsson, S., Molina, T., Adhvaryu, A., Christian, P., Labrique, A., Sugimoto, J., Shamim, A. A., & West, K. P. (2022, September). Protecting infants from natural disasters: The case of vitamin A supplementation and a tornado in Bangladesh. *Journal of Development Economics*, 158, 102914.
- Hair, N. L., Hanson, J. L., Wolfe, B. L., & Pollak, S. D. (2015). Association of child poverty, brain development, and academic achievement. *JAMA Pediatrics*, 169(9), 822–829.
- Hallegatte, S., Godinho, C., Rentschler, J., Avner, P., Knudsen, C., Lemke, J., & Mealy, P. (2023). *Within reach: Navigating the political economy of decarbonization*. World Bank.
- Hallegatte, S., Bangalore, M., Bonzanigo, L., Fay, M., Narloch, U., Rozenberg, J., & Vogt-Schilb, A. (2014). *Climate change and poverty—An analytical framework* (Policy Research Working Paper No. 7126). World Bank.

- Hallegatte, S., Bangalore, M., Bonzanigo, L., Fay, M., Kane, T., Narloch, U., Rozenberg, J., Treguer, D., & Vogt-Schilb, A. (2016). *Shock waves: Managing the impacts of climate change on poverty*. World Bank.
- Hallegatte, S., & Rozenberg, J. (2017, April 5). *Climate change through a poverty lens*. *Nature Climate Change*, 7, 250–256.
- Hallegatte, S., Vogt-Schilb, A., Bangalore, M., & Rozenberg, J. (2017). *Unbreakable: Building the resilience of the poor in the face of natural disasters*. *Climate Change and Development*. World Bank.
- Hanson, G. (2023). *Local labor market impacts of the energy transition: Prospects and policies* (Working Paper No. 30871). National Bureau of Economic Research.
- Harlan, S. H., Brazel, A. J., Prashad, L., Stefanov, W. L., & Larsen, L. (2006). Neighborhood microclimates and vulnerability to heat stress. *Social Science & Medicine*, 63(11), 2847–2863.
- Haushofer, J., & Fehr, E. (2014). On the psychology of poverty. *Science*, 344(6186), 862–867.
- Healy, A., & Malhotra, N. (2009). Myopic voters and natural disaster policy. *American Political Science Review*, 103(3), 387–406.
- Heggeness, M. L., & Hokayem, C. (2013). *Life on the edge: Living near poverty in the United States, 1966–2011* (SEHSD Working Paper). U.S. Census Bureau.
- Hendren, N., & Sprung-Keyser, B. (2020). A unified welfare analysis of government policies. *The Quarterly Journal of Economics*, 135(3), 1209–1318.
- Hernani-Limarino, W., Freije-Rodriguez, S., & Rozenberg, J., (Forthcoming). *Microsimulation approaches for the assessment of household welfare impacts of climate change and climate action* (Guidance note). World Bank.
- Hill, R. V., Kumar, N., Magnan, N., Makhija, S., De Nicola, F., Spielman, D. J., & Ward, P. S. (2019, January). Ex ante and ex post effects of hybrid index insurance in Bangladesh. *Journal of Development Economics*, 136, 1–17.
- Hill, R. V., & Narayan, A. (2020). *Covid-19 and inequality: A review of the evidence on likely impact and policy options* (Working Paper No. 3). Centre for Disaster Protection, London.
- Hill, R. V., Campero Peredo, A., & Tarazona, M. (2021). *The impact of pre-arranged disaster finance: Evidence gap assessment* (Working Paper No. 7). Centre for Disaster Protection, London.
- Hill, R. V., & Porter, C. (2017). Vulnerability to drought and food price shocks: Evidence from Ethiopia. *World Development*, 96, 65–77.
- Hirvonen, K., Machado, E. A., Simons, A. M., & Taraz, V. (2022, July). More than a safety net: Ethiopia's flagship public works program increases tree cover. *Global Environmental Change*, 75, 102549.
- Hoddinott, J., & Quisumbing, A. (2010). Methods for microeconomic risk and vulnerability assessment. In R. Fuentes-Nieva, & P. A. Seck (Eds.), *Risk, shocks, and human development: On the brink*, pp. 62–100. Palgrave Macmillan.
- Hoy, C., Kim, Y. S., Nguyen, M., Sosa, M., & Tiwari, S. (2023). *Building public support for reducing fossil fuel subsidies: Evidence across 12 middle-income countries* (Policy Research Working Paper No. 10615). World Bank.
- Hsiang, S. (2016). Climate econometrics. *Annual Review of Resource Economics*, 8(1), 43–75.

- Hsiang, S., Oliva, P., & Walker, R. (2019). *The distribution of environmental damages. Review of Environmental Economics and Policy*, 13(1), 83–103.
- Hultgren, A., Carleton, T., Delgado, M., Gergel, D. R., Greenstone, M., Houser, T., Hsiang, S., Jina, A., Kopp, R. E., Malevich, S. B., McCusker, K. E., Mayer, T., Nath, I., Rising, J., Rode, A., & Yuan, J. (2022). Estimating global impacts to agriculture from climate change accounting for adaptation. *SSRN Electronic Journal*.
- Huizinga, J., de Moel, H., & Szewczyk, W. (2017, April 12). *Global flood depth-damage functions: Methodology and the database with guidelines*. JRC Publications Repository.
- Hutton, G., Rehfuess, E., Tediosi, F., & Weiss, S. (2006). *Evaluation of the costs and benefits of household energy and health interventions at global and regional levels*. World Health Organization.
- Hurlbert, M., Krishnaswamy, J., Davin, E., Johnson, F. X., Mena, C. F., Morton, J., Myeong, S., Viner, D., Warner, K., Wreford, A., Zakieldeen, S., & Zommers, Z. (2019). Risk management and decision-making in relation to sustainable development. In P. R. Shukla, J. Skea, E., Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, ... J. Malley (Eds.), *Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*, pp. 673–800. Cambridge University Press.
- ILO. (2017). *How to measure and model social and employment outcomes of climate and sustainable development policies*. International Labour Organization.
- IMF. (2022). *World economic outlook: War sets back the global recovery*. International Monetary Fund.
- Inchauste, G., & Victor, D. (2017). *The political economy of energy subsidy reform. Directions in Development*. World Bank.
- IPBES. (2019). *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.
- IPCC. (2023a). *Health* [Factsheet derived from the IPCC Sixth Assessment Report by Working Group II – Impacts, Adaptation and Vulnerability]. Intergovernmental Panel on Climate Change.
- IPCC. (2023b). Summary for policymakers. In Core Writing Team, H. Lee, & J. Romero (Eds.), *Climate change 2023: Synthesis report. A report of the Intergovernmental Panel on Climate Change. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 1–34. Intergovernmental Panel on Climate Change.
- IPCC. (2022). Summary for policymakers. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate change 2022: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 3–36. Cambridge University Press.
- Jack, W., & Suri, T. (2014). Risk sharing and transactions costs: Evidence from Kenya's mobile money revolution. *The American Economic Review*, 104(1), 183–223.
- Jellema, J., Wai-Poi, M., & Afka, R. (2017). *The distributional impact of fiscal policy in Indonesia*. World Bank.

- Jensen, N. D., Barrett, C. B., & Mude, A. G. (2017, November). Cash transfers and index insurance: A comparative impact analysis from northern Kenya. *Journal of Development Economics*, 129, 14–28.
- Ivaschenko, O., Doyle, J., Kim, J., Sibley, J., & Majoka, Z. (2020). Does ‘Manna from Heaven’ help? The role of cash transfers in disaster recovery—lessons from Fiji after Tropical Cyclone Winston. *Disasters*, 44(3), 455–476.
- Kala, N., Balboni, C., & Bhogale, S. (2023, June). Climate Adaptation. *VoxDevLit*, 7.1.
- Kanbur, R. (2023). *What is the World Bank good for?* [Presentation]. EFI Africa Directors Inspirational Breakfast Series, Washington, DC.
- Karamba, W., Tong, K., & Salcher, I. (2022). *Cambodia poverty assessment: Toward a more inclusive and resilient Cambodia*. World Bank.
- Karlan, D., Osei, R., Osei-Akoto, I., & Udry, C. (2014). Agricultural decisions after relaxing credit and risk constraints. *The Quarterly Journal of Economics*, 129(2), 597–652.
- Karver, J., Lucchetti, L., Fruttero, A., Sajaia, Z., Nguyen, T., Oviedo, A. M., & Silvestri, A. (2023). *Behavioral diagnostic of sustainable heating transitions in the Western Balkans: Evidence from Bosnia & Herzegovina, Kosovo, North Macedonia, and Serbia*. World Bank.
- Kazianga, H., & Udry, C. (2006). Consumption smoothing? Livestock, insurance, and drought in rural Burkina Faso. *Journal of Development Economics*, 79(2), 413–446.
- Kochhar, N., & Knippenberg, E. (2023). *Droughts and welfare in Afghanistan* (Policy Research Working Paper No. 10272). World Bank.
- Kosmowski, F. (2018, May). Soil water management practices (terraces) helped to mitigate the 2015 drought in Ethiopia. *Agricultural Water Management*, 204, 11–16.
- Kulp, S. A., & Strauss, B. H. (2019). New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. *Nature Communications*, 10(1), 1–12.
- Koubi, V. (2019, May). Climate change and conflict. *Annual Review of Political Science*, 22, 343–360.
- Lassébie, J., Marcolin, L., Vandeweyer, M., & Vignal, B. (2021). *Speaking the same language: A machine learning approach to classify skills in Burning Glass Technologies data* (OECD Social, Employment and Migration Working Paper No. 263). OECD Publishing.
- Lavell, A., Oppenheimer, M., Diop, C., Hess, J., Lempert, R., Li, J., Muir-Wood, R., & Myeong, S. (2012). Climate change: New dimensions in disaster risk, exposure, vulnerability, and resilience. In C. B. Field, V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G.-K. Plattner, S. K. Allen, M. Tignor, & P. M. Midgley (Eds.), *Managing the risks of extreme events and disasters to advance climate change adaptation: Special report of Working Groups I and II of the Intergovernmental Panel on Climate Change*, pp. 25–64. Cambridge University Press.
- López-Calva, L. F., & Ortiz-Juarez, E. (2014, January). A vulnerability approach to the definition of the middle class. *Journal of Economic Inequality*, 12, 23–47.
- López-Calva, L. F., & Rodríguez-Castelán, C. (2016). *Pro-growth equity: A policy framework for the twin goals* (Policy Research Working Paper No. 7897). World Bank.

- Lustig, N. (Ed.). (2023). *Commitment to equity handbook: Estimating the impact of fiscal policy on inequality and poverty*. Brookings Institution Press.
- Lybbert, T. J., Barrett, C. B., Desta, S., & Layne Coppock, D. (2004). Stochastic wealth dynamics and risk management among a poor population. *The Economic Journal*, 114(498), 750–777.
- Macours, K. (2013). Volatility, agricultural risk, and household poverty: micro-evidence from randomized control trials. *Agricultural Economics*, 44(s1), 79–84.
- Mansur, A., Doyle, J., & Ivaschenko, O. (2018). Cash transfers for disaster response: lessons from Tropical Cyclone Winston. *Development Policy Centre Discussion Paper*, (67).
- Martin, R., de Preux, L. B., Wagner, U. J. (2014). The impact of a carbon tax on manufacturing: Evidence from microdata. *Journal of Public Economics*, 117, 1–14.
- Matlon, P. J. (1985). *Annual report of ICRISAT/Burkina economics program*. International Crops Research Institute for the Semi-arid Tropics (ICRISAT).
- Mauerman, M., Ross, C., Ilboudo Nébié, E., Anderson, W., Jensen, N., & Chelanga, P. (2023, April). The long-term impact of multi-season droughts on livestock holdings and pastoralist decision-making in Marsabit, Kenya. *Journal of Arid Environments*, 211, 104928.
- McPeak, J. G., & Barrett, C. B. (2001). Differential risk exposure and stochastic poverty traps among East African pastoralists. *American Journal of Agricultural Economics*, 83(3), 674–679.
- Mealy, P. (2022). *Capturing benefits of the green transition: Green competitiveness and jobs in Brazil* [Background paper for the Brazil CCDR]. World Bank.
- Mendelsohn, R., Nordhaus, W. D., & Shaw, D. (1994). The impact of global warming on agriculture: A Ricardian analysis. *The American Economic Review*, 84(4), 753–771.
- Metcalf, G. (2019). *On the economics of a carbon tax for the United States*. Brookings Papers on Economic Activity.
- Miguel, E. (2005). Poverty and witch killing. *The Review of Economic Studies*, 72(4), 1153–1172.
- Miller, F., & Dun, O. (2019). Resettlement and the environment in Vietnam: Implications for climate change adaptation planning. *Asia Pacific Viewpoint*, 60(2), 132–147.
- Mobarak, A. M., & Rosenzweig, M. R. (2013). Informal risk sharing, index insurance, and risk taking in developing countries. *The American Economic Review*, 103(3), 375–380.
- Mohapatra, S., Joseph, G., & Ratha, D. (2012, April). Remittances and natural disasters: Ex-post response and contribution to ex-ante preparedness. *Environment, Development, and Sustainability*, 14, 365–387.
- Molini, V., & Pavelesku, D. (2018). *Poverty and social impact analysis Tunisia: The impact of reductions in electricity and gas subsidies*. World Bank Group.
- Montgomery, L. E., Kiely, J. L., & Pappas, G. (1996). The effects of poverty, race, and family structure on US children's health: Data from the NHIS, 1978 through 1980 and 1989 through 1991. *American Journal of Public Health*, 86(10), 1401–1405.
- Mukherjee, A., Okamura, Y., Gentilini, U., Gencer, D., Almenfi, M., Kryeziu, A., Montenegro, M., & Umapathi, N. (2023). *Cash transfers in the context of energy subsidy reform: Insights from recent experience*. Energy Subsidy Reform in Action Series. World Bank.

- Murdiyarso, D., Purbopuspito, J., Kauffman, J. B., Warren, M. W., Sasmito, S. D., Donato, D. C., Manuri, S., Krisnawati, H., Taberima, S., & Kurnianto, S. (2015). The potential of Indonesian mangrove forests for global climate change mitigation. *Nature Climate Change*, 5(12), 1089–1092.
- New, M., Reckien, D., Viner, D., Adler, C., Cheong, S.-M., Conde, C., Constable, A., Coughlan de Perez, E., Lammel, A., Mechler, R., Orlove, B., & Solecki, W. (2022). Decision-making options for managing risk. In H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama (Eds.), *Climate change 2022: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 2539–2654. Cambridge University Press.
- Nguyen, T., & Torrachi, F. (2017). *Impacts of electricity tariff reforms on energy affordability in the Western Balkans*. World Bank Group.
- Nico, G., & Christiaensen, L. (2023). *Jobs, food, and greening: Exploring implications of the green transition for jobs in the agri-food system* (Jobs Working Paper No. 75). World Bank Group.
- OECD. (2023). *Job creation and local economic development 2023: Bridging the great green divide*. OECD Publishing.
- Olivier, A., Matytsin, M., & Gencer, D. (2023). *Distributional analysis for informing energy subsidy reforms: Review of recent approaches*. Energy Subsidy Reform in Action Series. World Bank.
- Ortiz-Bobea, A., Ault, T. R., Carrillo, C. M., Chambers, R. G., & Lobell, D. B. (2021). Anthropogenic climate change has slowed global agricultural productivity growth. *Nature Climate Change*, 11(4), 306–312.
- Oppenheimer, M., Glavovic, B. C., Hinkel, J., van de Wal, R., Magnan, A. K., Abd-Elgawad, A., Cai, R., Cifuentes-Jara, M., DeConto, R. M., Ghosh, T., Hay, J., Isla, F., Marzeion, B., Meyssignac, B., & Sebesvari, Z. (2019). Sea level rise and implications for low-lying islands, coasts, and communities. In H.-O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, & N. M. Weyer (Eds.), *IPCC special report on the ocean and cryosphere in a changing climate*, pp. 321–445. Cambridge University Press.
- Osborne, T., Pachón, M. C., & Araya, G. E. (2014). *What drives the high price of road freight transport in Central America?* (Policy Research Working Paper No. 6844). World Bank.
- Pape, U. J., & Ali, R. (2023). Indonesia poverty assessment—Pathways towards economic security. World Bank.
- Pape, U. J., & Wollburg, P. R. (2019). *Impact of drought on poverty in Somalia* (Policy Research Working Paper No. 8698). World Bank.
- Pant, R., Thacker, S., Hall, J. W., Alderson, D., & Barr, S. (2018). Critical infrastructure impact assessment due to flood exposure. *Journal of Flood Risk Management*, 11(1), 22–33.
- Pao-Yu, O., Brauers, H., & Herpich, P. (2020). Lessons from Germany's hard coal mining phase-out: Policies and transition from 1950 to 2018. *Climate Policy*, 20(8), 963–979.
- Person, B., Loo, J. D., Owuor, M., Ogame, L., Jefferds, M. E. D., & Cohen, A. L. (2012). “It is good for my family's health and cooks food in a way that my heart loves”: Qualitative findings and implications for scaling up an improved cookstove project in rural Kenya. *International Journal of Environmental Research and Public Health*, 9(5), 1566–1580.

- Pople, A., Hill, R., Dercon, S., & Brunckhorst, B. (2021). *Anticipatory cash transfers in climate disaster response*. Centre for the Study of African Economies.
- Porter, C., & White, E. (2016). *Potential for application of a probabilistic catastrophe risk modelling framework to poverty outcomes: General form vulnerability functions relating household poverty outcomes to hazard intensity in Ethiopia* (Policy Research Working Paper No. 7717). World Bank
- Posadas, J., Alatas, H., & Granata, M. J. (2020). *Indonesia's occupational tasks and skills from occupational employment demand to tasks and skills requirements 2020*. World Bank Group.
- Rafaty R., Dolphin, G., & Pretis, F. (2021). *Carbon pricing and the elasticity of CO2 emissions* (Working Paper 21–33). Resources for the Future.
- Rahman, S., & Akter, S. (2014). Determinants of livelihood choices. *Journal of South Asian Development*, 9(3).
- Reardon, T. (1997). Using evidence of household income diversification to inform study of the rural nonfarm labor market in Africa. *World Development*, 25(5), 735–747.
- Robayo-Abril, M. (Forthcoming). *Labor market search, informality, and human capital shocks*.
- Robayo-Abril, M., & Barroso, R. (2022). *El Salvador Systematic Country Diagnostic: Addressing vulnerabilities to sustain poverty reduction and inclusive growth*. World Bank.
- Robayo-Abril, M., Rude, B., Cadena, K., & Espino, I. (2023). *Honduras poverty assessment: Toward a path of poverty reduction and inclusive growth*. World Bank.
- Rodriguez-Castelan, C., Araar, A., Malasquez, E. A., Olivieri, S., & Vishwanath, T. (2019). *Distributional effects of competition: A simulation approach* (Policy Research Working Paper No. 8838). World Bank.
- Rosenzweig, M. R., & Udry, C. (2016). *External validity in a stochastic world* (Yale University Economic Growth Center Discussion Paper No. 1054).
- Ruggeri Laderchi, C., Spatafora, N. L., Sudhir, S., & Zaidi, S. (2017). *Riding the wave: An East Asian miracle for the 21st century*. *World Bank East Asia and Pacific Regional Report*. World Bank Group.
- Saczewska-Piotrowska, A. (2016). Near poverty definition, factors, prediction. *Econometrics: Advances in Applied Data Analytic*, 4(54), 82–94.
- Sandmo, A. (1971). On the theory of the competitive firm under price uncertainty. *The American Economic Review*, 61(1), 65–73.
- Saussay, A., Sato, M., Vona, F., & O’Kane, L. (2022). *Who’s fit for the low-carbon transition? Emerging skills and wage gaps in job and data* (Grantham Research Institute on Climate Change and the Environment Working Paper No. 381).
- Schwaab, J., Meier, R., Mussetti, G., Seneviratne, S., Bürgi, C., & Davin, E. L. (2021). The role of urban trees in reducing land surface temperatures in European cities. *Nature Communications*, 12(1), 1–11.
- Sekhri, S., & Storeygard, A. (2014, November). Dowry deaths: Response to weather variability in India. *Journal of Development Economics*, 111, 212–223.

- Seneviratne, S. I., Nicholls, N., Easterling, D., Goodess, C. M., Kanae, S., Kossin, J., Luo, Y., Marengo, J., McInnes, K., Rahimi, M., Reichstein, M., Sorteberg, A., Vera, C., & Zhang, X. (2012). Changes in climate extremes and their impacts on the natural physical environment. In C. B. Field, V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G.-K. Plattner, S. K. Allen, M. Tignor, & P. M. Midgley (Eds.), *Managing the risks of extreme events and disasters to advance climate change adaptation: Special report of Working Groups I and II of the Intergovernmental Panel on Climate Change*, pp. 109–230. Cambridge University Press.
- Seo, S. N., & Mendelsohn, R. (2008). Measuring impacts and adaptations to climate change: A structural Ricardian model of African livestock management. *Agricultural Economics*, 38(2), 151–165.
- Severen, C., Costello, C., & Deschenes, O. (2018, May). A forward-looking Ricardian approach: Do land markets capitalize climate change forecasts? *Journal of Environmental Economics and Management*, 89, 235–254.
- Strobl, E., & Spencer, N. (2024). Modeling the impact of extreme climate events on household welfare: A review of the empirical challenges.
- Stoeffler, Q., Carter, M., Guirking, C., & Gelade, W. (2022). The spillover impact of index insurance on agricultural investment by cotton farmers in Burkina Faso. *World Bank Economic Review*, 36(1), 114–140.
- Tanaka, T., Camerer C., & Nguyen, Q. (2010). Risk and time preferences: Linking experimental and household survey data from Vietnam. *The American Economic Review*, 100(1), 557–571.
- Tesfaye, W., & Tirivayi, N. (2020, January). Crop diversity, household welfare and consumption smoothing under risk: Evidence from rural Uganda. *World Development*, 125, 104686.
- Triyana, M., Jiang, A. W., Hu, Y., & Naoaj, M. S. (2024). *Climate shocks and the poor: A review of the literature* (Policy Research Working Paper 10742). World Bank.
- Valero, A., Li, J., Muller, S., Riom, C., Nguyen-Tien, V., & Draca, M. (2021). *Are 'green' jobs good jobs? How lessons from the experience to-date can inform labor market transitions of the future*. Grantham Research Institute on Climate Change and the Environment and Centre for Economic Performance, London School of Economics and Political Science.
- Van der Mensbrugghe, D. (2010). *The ENVironmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) model, version 7.1*. World Bank.
- Van der Mensbrugghe, D. (2020). *The Mitigation, Adaptation, and New technologies Applied General Equilibrium (MANAGE) model, version 2.0g*. GTAP Technical Paper. Center for Global Trade Analysis, Purdue University.
- Van der Ree, K. (2019). Promoting green jobs: Decent work in the transition to low-carbon, green economies. In C. Gironde, & G. Carbonnier (Eds.), *The ILO @ 100: Addressing the past and future of work and social protection*, pp. 248–272. Brill.
- Vona, F., Marin, G., Consoli, D., & Popp, D. (2018). Environmental regulation and green skills: An empirical exploration. *Journal of the Association of Environmental and Resource Economists*, 5(4).
- Wiseman, W., Van Domelen, J., & Coll-Black, S. (2010). *Designing and implementing a rural safety net in a low-income setting: Lessons learned from Ethiopia's Productive Safety Net Program 2005–2009*. World Bank.
- Wollburg, P., Hallegatte, S., & Mahler, D. G. (2023). Ending extreme poverty has a negligible impact on global greenhouse gas emissions. *Nature*, 623(7989), 982–986.
- World Bank. (2012). *Carbon sequestration in agricultural soils*. World Bank.

- World Bank. (2016). *The Uganda poverty assessment report 2016: Farms, cities, and good fortune—Assessing poverty reduction in Uganda from 2006 to 2014*. World Bank.
- World Bank. (2018). *Poverty and shared prosperity 2018: Piecing together the poverty puzzle*. World Bank.
- World Bank. (2019a). *Air quality management in Poland* [Final report]. World Bank.
- World Bank. (2019b). *Aspiring Indonesia: Expanding the middle class*. World Bank.
- World Bank. (2019c). *Burkina Faso rural income diagnostic*. World Bank.
- World Bank. (2020). *Poland catching-up regions: Towards robust, scalable, and inclusive clear air program for all*. World Bank.
- World Bank. (2021). *The gradual rise and rapid decline of the middle class in Latin America and the Caribbean*. World Bank.
- World Bank. (2022a). *Brazil poverty and equity assessment: Looking ahead of two crises*. World Bank.
- World Bank. (2022b). *China Country Climate and Development Report. CCDR Series*. World Bank.
- World Bank. (2022c). *2022 Vietnam poverty & equity assessment: From the last mile to the next mile*. World Bank.
- World Bank. (2022d). *Kazakhstan Country Climate and Development Report. CCDR Series*. World Bank.
- World Bank. (2022e). *G5 Sahel Region Country Climate and Development Report. CCDR Series*. World Bank.
- World Bank. (2022f). *Pakistan Country Climate and Development Report. CCDR Series*. World Bank.
- World Bank. (2022g). *Peru Country Climate and Development Report. CCDR Series*. World Bank.
- World Bank. (2022h). *Poverty and shared prosperity 2022: Correcting course*. World Bank.
- World Bank. (2022i). *Progress, setbacks, and uncertainty: Effects of Covid-19 and coup on poverty in Myanmar* [Myanmar Poverty Synthesis Note]. World Bank.
- World Bank. (2023a). *Cambodia Country Climate and Development Report. CCDR Series*. World Bank.
- World Bank. (2023b). *Colombia Country Climate and Development Report. CCDR Series*. World Bank.
- World Bank. (2023c). *Green jobs: Upskilling and reskilling Vietnam's workforce for a greener economy*. World Bank Group.
- World Bank. (2023d). *Rising strong: Peru poverty and equity assessment*. World Bank.
- World Bank. (2023e). *Tunisia Country Climate and Development Report. CCDR Series*. World Bank.
- World Bank, & IMF. (2022). *Achieving climate and development goals: The financing question* [Document for the October 14, 2022, Development Committee Meeting]. Development Committee.
- Zaveri, E., Damania, R., & Engle, N. (2023). *Droughts and deficits: The global impact of droughts on economic growth* (Policy Research Working Paper No. 10453). World Bank.
- Ziter, C. D., Pedersen, E. J., Kucharik, C. J., & Turner, M. G. (2019). Scale-dependent interactions between tree canopy cover and impervious surfaces reduce daytime urban heat during summer. *Proceedings of the National Academy of Sciences*, 116(15), 7575–7580.

