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The Impact of Climate Change on Work

Lessons for Developing Countries

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Abstract

What is the impact of climate change on labor? Reviewing the evidence, this paper finds five areas of potential impact. Climate change may have an immediate effect on labor demand, labor supply and time allocation, on-the-job productivity, and income and vulnerability among the self-employed. In the medium term, climate change may lead to a reallocation of labor across economic activities and across space. Impact estimates typically rely on fixed effect estimation. These estimates require care when interpreted as they typically reflect the short-term direct impact of past events and abstract from potential adaptation. The paper discusses emerging work trying to address this, analyzing the responses by firms, farms, households, and workers. Together, the existing evidence points toward six potential areas of government response. Potential labor policies include green jobs, green skills, labor-oriented adaptation, flexible work regulation, labor market integration, and social protection. The paper concludes by setting out avenues for future research in this field.

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The Impact of Climate Change on Work: Lessons for Developing Countries

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1. Introduction

Work is the main source of income for most people around the world, and in particular for the poor. As a primary factor of production, labor also plays a key role in economic growth. Yet our understanding of how climate change impacts labor remains scattered. This paper takes stock of what we know, distinguishing five ways in which climate change may affect labor. We discuss limitations and challenges with existing estimates, underlining the need for careful interpretation. A central issue of concern is the omission of adaptation, and we discuss recent insights on the responses by firms, farms, households and workers. Together, the evidence suggests several potential areas of government response. We discuss possible labor policies and ways forward for research.

A growing literature establishes the impact of climate change on general economic performance. Weather variation – measured in terms of temperature, precipitation, or climate change related weather events – is estimated to lower economic output, with the largest expected impacts for low- and middle-income countries.[i] Changes in weather also increase or deepen poverty, in particular in rural and exposed areas, and among vulnerable groups.[ii]

Labor represents a possible key channel through which climate change affects economic performance and poverty. Reviewing the most rigorous existing evidence, we distinguish five potential areas for the impact of climate change on labor: labor demand, labor supply and time allocation, on-the-job productivity, and income and vulnerability among the self-employed. In the medium-term climate change may lead to a reallocation of labor across economic activities and across space.

The studies we consider follow a common estimation strategy, with impact estimates typically obtained through fixed effect estimation. These estimates generally capture the short-term, immediate effects of past events and do not account for potential adaptation. They might therefore overestimate long-term effects, in particular if substantial adaptation is anticipated. Conversely, they might underestimate long-term impacts, when they fail to consider effects across the economy, or if climate change worsens, i.e. realized past events are a poor predictor for future occurrences. While we mention research aimed at tackling the latter two concerns, mainly through general equilibrium analysis and simulation of future outcomes, where appropriate, our primary interest lies in the emerging adaptation research that examines responses by firms, farms, households and workers.

This leads us to the question how governments can, and do, respond. There has been limited research investigating the impact of general climate change policies on labor outcomes, highlighting the need for more thorough examination. In the realm of labor-targeting climate change policies, we distinguish six potential areas where governments can take action: green jobs, green skills, labor-oriented adaptation, flexible work regulation, labor market integration, and social protection.

Our review demonstrates the impact of climate change on labor to be a growing area of research, where much is to be discovered. We conclude by setting out avenues for future research.

Section 2 reviews the evidence, starting with a note on methods used and challenges of identification, before distinguishing the five ways in which climate change may impact labor. Section 3 discusses how agents respond, commencing with an examination of analytical methods, followed by a discussion of how firms, farms, households and workers respond. A subsequent section examines government response. The concluding section discusses ways forward for research and the evaluation of policies in this field.

2. The impact of climate change on labor

2.1. Methods and identification

This overview focuses on studies that estimate the impact of climate change on labor outcomes using regression analysis, typically a variation of the following form:

$$Y_{ijt} = \alpha + \beta T_{ijt}^{e} + C_{ijt}^{e}\Gamma + X_{ijt}\Pi + \mu_i + \mu_j + \gamma_{jt} + \varepsilon_{ijt} \quad (1)$$

Where Y_{ijt} is the labor variable of interest, and β is the impact of climate change – often temperature – in area *j* at time *t*, to which worker *i* (in micro studies) or sector or country *i* (in meso or macro studies) is exposed (T_{ijt}^{e}). Some papers look beyond temperature, at precipitation, or other climate change events. C_{ijt}^{e} reflects other climate change events that may be included or not in the regression. X_{ijt} are individual worker (or sector or country) characteristics that affect Y_{ijt}. μ_i and μ_j are unobserved individual and location fixed effects respectively (which are combined in some studies), and γ_{jt} is a time trend.[iii] This estimation typically combines longitudinal data on economic outcomes[iv] with climate data from weather station, gridded, satellite, or other secondary sources and exploits short-run, *plausibly* exogeneous variation in climate to estimate impact on labor outcomes of interest.

Studies differ in the variables they include on the right-hand side. Research focusing on temperature typically control for other climate events like precipitation. The observed subject characteristics that are included as control variables also vary. Including fixed effects and time trends yields a more robust estimate.

The next sections zoom in on specific left hand side labor variables of interest, one at a time: demand, supply, productivity, income, allocation, and migration. The studies on allocation compare estimates from across different sectors. Throughout the estimations, challenges remain in obtaining estimates of β that reflect causal impact, given the non-experimental nature of the data. We see five issues of concern.

First, the temperature (or other climate event) to which workers are actually exposed remains unobserved. Locally measured temperature (or climate change event) serves as a proxy.[v] This will affect precision, and can lead to biased estimation, if the exposed temperature is very different from the observed one.[vi] In general, studies seem to be aware of this concern and pay attention to avoid major mismeasurement of this nature.

A second limitation is that the studies estimate historic and short term, immediate, impacts. Firms, workers, markets and regulators, may adapt to higher temperature and other climatic changes, possibly reducing their impact on labor. The extent to which adaptation takes place is a topic of increasing attention and the subject of a nascent literature, which we discuss in the section on response. In general, our understanding in this area remains limited. Adaptation will also be heterogenous in form and in the time it takes to respond. In some countries (low income), areas (rural), and sectors (agriculture, outdoor) adaptation is likely to be slower. Nevertheless, because accounting for adaptation remains a challenge, most of today's estimates need to be seen as short-term impacts. They may be an upper bound if there is increased adaptation in the future; they may be a lower bound if changes in climate become more severe, leading to higher impacts.

To address the uncertainty about future trends, a separate strand of papers looks at projections for the future, using simulation-based approaches starting from predicted temperature and current economic outcomes. They use a distinct type of analysis from the one set out above. Their inference is informative, providing a sense of the general trends, albeit under specific assumptions (Stern, 2008). These estimates are not the focus of attention in this paper, although we include the results from a few overview studies because of their informative nature – we mention these explicitly as simulation studies.

A third shortcoming is that the estimates are obtained for partial equilibrium. General equilibrium effects – changes across the economy that come about from linkages between economic activities – are neglected. Specific studies try to shed light on GE effects using distinct methodologies, including Computable General Equilibrium (CGE) and Dynamic General Equilibrium models or Input-Output (I/O) analysis. While these studies are useful to get some idea of data patterns, their results are quite sensitive to the underlying assumptions.[vii] We mention these studies where useful, although they are not central to our overview.

Fourth, while some research discusses potential omitted variables, other studies don't. Yet in the absence of experimental data, estimates may be biased due to omitted variables. One key unobservable of high importance is the capacity for adaptation. Firms or workers with some characteristics – e.g. more profitable, wealthier – may be quicker at taking adaptive measures, thereby reducing impact. Other omitted variables, including climate variables, may also matter.[viii]

Fifth, while location fixed effects help to obtain a more robust impact estimate, they do not shed light on the salient aspects of context. Which characteristics of the local economy and labor market matter most, is important for policy design. One way to address this is to carry out subsample analysis, breaking down the results for different subgroups or localities along pre-meditated dimensions of interest. Another approach is to focus a study on specific setting, which allows explicitly taking into account salient characteristics, leading to richer interpretation, and highlighting the gaps, identifying key directions for future work.[ix]

Despite these limitations, the estimated impacts are the best we have for now. Comparison across the most rigorous studies can help assess the robustness of these estimates. Nevertheless, critical assessment and meticulous interpretation remain key, as discussed throughout the next sections.

2.2. Labor demand

Climate change is expected to affect the demand for labor through diverse channels. Where climate change reduces output, as the evidence suggests for specific sectors, including agriculture, derived demand for labor will typically go down. At the same time, as the world moves toward greener production, demand for labor in carbon intensive activities, like nonrenewable energy, is anticipated to decline, while that in green activities is set to increase. As it stands, we possess an incomplete comprehension of the net effect of climate change on labor demand. To gain a clearer understanding, sectoral analysis is needed. In what follows we provide a summary of expected climate impacts on labor demand in selected sectors.

2.2.1. Agriculture

Agricultural output can be affected in several ways. Growing evidence documents how increased heat reduces agricultural output in low- and middle-income countries, varying between 5% and 25%, depending on the crop, region, and time span considered.[x] Increased rainfall is often positively related to agricultural output.[xi] Exposure to cyclones bears negative impacts.[xii]

Direct impacts on the demand for labor have been observed across several developing country settings. In Mexico extreme heat is associated with a 1.4% decline in rural employment over a 28-year period, driven by weather-impacted agricultural yield losses. Reductions are largest for non-farm labor, as a result of the reduced demand for non-agricultural goods (Jessoe et al., 2018).[xiii] In El Salvador total corn production declined by as much as 2.8% for an additional week of high temperature during the harvest season (Ibanez et al., 2022). Agricultural producers adjusted by using more household labor and fewer hired workers, who either migrate or change to a non-agricultural job. In Brazil a 1-standard deviation increase in excess aridity reduced planted and harvested areas by 1.6% and 2.7%, respectively, during 2000-2010. Agricultural employment fell by around 11% in line with the negative impact on agriculture output (Albert et al., 2021). In China, a 1°C increase in temperature is associated with 7% reduced farm work across rural communities (Huang et al., 2020).

Reduced demand for labor may especially affect women. In India, after a drought shock, women were 7% less likely to be in employment compared to men (1.2 percentage points for women versus 0.5 percentage points for men), spend 29% more days seeking work, and have 20% lower non-farm workdays; those in farm work see their real earnings fall by 38% compared to 3.4% for men (Afridi et al., 2022).

Most studies in agriculture suffer from at least two of the limitations mentioned in section 2.1. First, they abstract from adaptation behavior of farmers, which is likely to temper long term impacts A handful of studies accounts for adaptation and consider multiple seasons, but the findings are disparate. Chinese farmers use more machines to compensate for the shortage of labor arising from extreme hot weather, and this offsets nearly 47% of the short-run effects on agriculture yield over a 35-year period (Chen and Gong, 2021). One attractive method to study adaptation exists of comparing short-term panel estimates to long term difference estimates. Exploiting large variation in weather across time and counties in the US, one study finds minimal long-run adaptation in terms of unchanged agricultural inputs and staying with same crop, while the cultivated area declined (Burke and Emerick, 2016). The limited adaptation is understood to arise from farmers either not being fully aware of a changing climate, or recognizing the need for adaptation but unable to implement adjustment.

A second shortcoming is that these studies rarely look at labor outcomes beyond agriculture, and in doing so, ignore labor mobility as a margin of adjustment. When labor is mobile (across sectors or geographies) long-run impacts may be considerably smaller compared to the estimated short-run effects. Section 2.6 zooms in on the reallocation of labor.

2.2.2. Industry

Climate impacts on non-agricultural output tend to be more pronounced for developing countries, and stem primarily from hot weather and extreme heat. Overall, industrial value-added is found to shrink by 2% for every 1°C warming, but only in low-income countries (Dell et al., 2012; Hsiang, 2010). Precipitation effects are less robust, though there is variation by region (Dell et al., 2012). These impacts seem to affect industrial exports from low-income to high-income economies, which decline by 2.4% for a 1°C temperature rise but do not vary with changes in precipitation (Jones and Olken, 2010).

Employment in heat exposed industries has received special attention in the literature. The few studies for developing countries typically concentrate on output, rather than employment, and find that output elasticity of labor is a primary mechanism for the observed negative effects of higher temperature. In India a 1°C warming in daily temperature depresses annual firm output by 2.1% across manufacturing nationwide over 15 years; this seems to be driven by reductions in the output elasticity of labor, rather than capital or other factors of production (Somanathan et al., 2021). Firm-level evidence from China confirms high temperature to affect sectoral output due to heat exposure: an additional hot day (> 90°F, 32°C) negatively affects output of almost half of the two-digit industrial sectors in China, including both labor-intensive and capital-intensive sectors, with notable heterogeneity in the magnitude of impact. For example, in timber manufacturing, output is expected to fall by 1.26% due to an additional hot day, while in nonmetal mining it would reduce by 1%. Impact is insignificant in medicine manufacturing and smelting of nonferrous metals, among others. High-tech industry output is insensitive to temperatures between 80°F–90°F (27°C–32°C) but sensitive to increase beyond that, while low-tech industry output is negatively impacted above any of these temperatures. These effects are large in economic terms: when assuming no additional adaptation, Chinese manufacturing output would be expected to fall by 12% annually (Zhang et al., 2018). These findings are in line with in-depth research for the US on employment loss in heat-exposed industries (Behrer and Park, 2017).[xiv]

The impact of cyclones on industrial output varies by sector and over time. In the Caribbean, one standard deviation increase in the exposure to cyclones is negatively related to output in mining and utilities (-0.9%), but positively related to construction after the event (+1.4%) (Hsiang, 2010). In India,[xv] these events reduced 3% of firm sales, destroyed 2% of firm assets, but had no impact on salaries or labor inputs across a panel of manufacturing firms between 1995 and 2006. Overall, these impacts tend to be short-lived and disappear after a year, with better-performing industries recovering faster (Pelli et al., 2023).

As with the research on agriculture, the above studies have two important caveats. First, they tend to concentrate on immediate, short term, impact. Second, they typically do not account for impacts outside the sector, which may be considerable. Section 2.6

2.2.3. Energy

Demand for energy is expected to increase with climate change, reflecting consumers' short-term response and long-term adaptation.[xvi] In Mexico, each additional day >90°F (32°C) increases monthly electricity consumption by 3.2%. As incomes rise, AC ownership increases with temperature by 3 and 27 percentage points, in cool and warm places, respectively, for a $10,000 increase in annual household income (Davis and Gertler, 2015).[xvii]

Most research on the energy sector concentrates on the expected impact of the shift towards green energy, following the global move towards low carbon, rather than the impact of climate change events themselves. Replacing fossil fuel with renewable energy will lead to job destruction in carbon-intensive industries and job creation in low-carbon sectors.[xviii] Existing evidence suggests a positive net employment effect in the energy sector for this climate transition. Because changes in energy have immediate effects across multiple sectors, many of these studies take a wider sector approach and focus on simulation of future outcomes.

An ex-ante I/O simulation indicates that if 139 countries were to convert 100% to clean energy from wind, water, and solar by 2050, 27.7 million jobs could be lost in high-carbon sectors such as oil, gas, coal, and biofuel, while approximately 52 million full-time jobs could be created (25.4 million construction jobs and 26.6 million operation and maintenance jobs), resulting in a net gain of 24.3 million full-time jobs in the sector (Jacobson et al., 2017). Another study simulates the direct employment capability of power plants across the world and finds that renewables can generate between 0.1 to 4 job-years per GWh on average versus 0.1 to 2.4 job-years per GWh for non-renewable power plants (Barros et al., 2017).

A regional CGE model for South Africa that analyzes the impact of a smaller share of coal in the energy supply mix finds an anticipated decline in employment in coal-producing regions, accompanied by an increase in other regions due to the expansion of non-fossil fuel power generation, assuming labor mobility is relaxed (Bohlmann et al., 2019). For the Middle East region, an Integrated Assessment Model (IAM) simulation finds that the large-scale deployment of renewables required to meet the region's GHG emissions reduction targets, needs a direct workforce of up to 180,000 and indirect workforce of up to 115,000 jobs, in wind, solar Photovoltaic (PV), and Concentrated Solar Power (CSP), depending on how much of the technology is manufactured locally—with the number of direct jobs created per year nearly reaching 18,000 for wind and well over 90,000 for both PV and CSP (Van der Zwaan et al., 2013).

While these simulation-based studies produce useful insights, their findings are highly sensitive to the model's assumptions and specifications. Recent meta-analysis confirms the sensitivity of estimated net employment effects of the energy transition to the specific method applied.[xix] Rigorous econometric estimation, following a specification like equation (1), for the energy sector itself remains scarce. Simulation methods themselves are also open to improvement.[xx]

2.2.4. Service

Services exposed to extreme weather conditions will be strongly affected. The transport sector is particularly vulnerable to heat extremes, heavy rains and flooding. Extensive adaptation of infrastructure, operations and service provision will likely be needed to mitigate impact (Sims et al., 2014). The net employment effect in this sector remains understudied globally. Evidence from the US indicates that transportation payroll expenses declined significantly in hotter than usual years, though it remains unclear whether this effect stems from reduced labor supply or decreased demand for transportation (Behrer and Park, 2017).

Tourism is another service exposed to climate risks. In South Africa, informal workers in tourism-related subsectors in provinces with high tourist activity face the greatest vulnerability to drought: overall employment in these areas declined by 1.2 percentage points, and transport sector employment declines by 0.3 percentage points, for a 1-standard deviation increase in measured drought (Gray et al., 2023).

Similar to the energy sector, the transport industry is vulnerable to both climate-related conditions and the risks associated with climate transition – think economywide carbon pricing, climate-smart transport policies, new transportation solutions, among others. As one of the leading contributors to carbon emissions, responsible for 24% of CO2 emissions from fuel combustion on a global scale, the transport sector is expected to undergo a significant transformation (IEA, 2020). These long term and far reaching effects are often overlooked in analysis, but are crucial for shaping effective policies. Section 3.3.1 discusses examples of government response, including carbon tax and energy pricing, and their impact on employment.

2.3. Labor supply and time allocation

Changes in climate may affect labor supply and time use in various ways. First, weather conditions may encourage worker absenteeism. In India, a rise in the 10-day average temperature by 1°C WBGT[xxi] increased the probability of absenteeism among steel workers by 2% and among garment workers by 10%, but not for piece rate workers in cloth-weaving factories (Somanathan et al., 2021). Workers in Chinese manufacturing, however, are not more absent on hotter days (Cai et al., 2018).[xxii]

Weather conditions may also encourage shirking. The quality of reported data among Demographic and Health Survey (DHS) interviewers declined significantly on hot days, with more missing responses per interview on average, while the total number of interviews conducted per interviewer remained unchanged (LoPalo, 2023).[xxiii]

Second, workers may adjust the distribution of work time in response to weather shocks. In one example work time is reallocated from farm to off-farm work. Indian households that experienced a persistent annual decline in farm income due to drying up wells (caused by climate change) are 12 percentage points more likely to derive income from off-farm employment. These added earnings compensate for income lost, leaving total household revenue unaffected (Blakeslee et al., 2020). Neither work related migration nor employment in nearby villages, nor changes in agricultural practices, played a similarly large role in offsetting the fall in income. Identical shifts to non-farm activity have been observed in rural China.[xxiv] Rainfall shocks induce analogous behavioral patterns. In Brazil more work hours are allocated to non-agricultural activities at times of negative rainfall shocks, with stronger effects for households in low-income municipalities (Branco and Feres, 2021).

In some cases, workers seem to reallocate time between leisure and labor. Workers in heat-exposed industries in the US reduce their daily labor supply by as much as 1 hour at temperatures above 85°F (29°C); this reduced work time is primarily replaced by indoor leisure (Graff Zivin and Neidell, 2014).[xxv] In another US study male workers labor 30 minutes longer on bad weather or rainy days (up to 48 minutes in dry regions), and reduce work time on the day following rainy day to make up for the previous day's lost leisure (Connolly, 2008). It is unclear whether shifting activities across time is as common in developing countries, as the existing evidence is mixed. In rural China, more growing-season Harmful Degree Days – defined as days with temperatures above 32°C – increases the probability of a time shift to leisure for men (Huang et al., 2020). The earlier mentioned DHS interviewers work more hours per day during hotter than usual periods.[xxvi]

Labor supply response may also vary by gender. Women tend to have less opportunity to diversify into other tasks at times of weather shocks, possibly exacerbating existing gender gaps in the labor market.[xxvii]

Together these studies suggest that workers may adapt their labor supply in the short term in response to changes in climate. Most of the current studies abstract from adaptation, which remains understudied.[xxviii]

A growing literature studies the possible mechanisms behind the observed short-term changes in labor supply. Early work, primarily based on macro analysis, conjectured the decline in the temperature sensitive agricultural sector as a major factor (Jones and Olken, 2010; Dell et al., 2012). Recent evidence underlines the importance of health (Deschenes, 2014).

Exposure to extreme temperature has a direct impact on the body: it strains cardiovascular, respiratory, and cerebrovascular systems. This also leads to increased mortality risks. An additional hot day with a mean temperature above 36°C increases. annual mortality in India by 0.75% (Burgess et al., 2011). In the US, the number of days with temperature above 90°F (> 32°C) is associated with 0.11% increase in mortality, after accounting for adaptation at home (Deschenes and Greenstone, 2011), while annual mortality is estimated to increase by up to 3% by 2100.[xxix] Hot-day related fatalities fall with access to residential air conditioning (Barreca et al., 2016). Average temperature is also positively related to suicide rates and negatively related to mental well-being, with adaptation (like air conditioning) having little impact. A 1°C increase in the monthly average temperature increases suicide rates in Mexico 2.1%, compared to 0.7% in the US (Burke et al., 2018).[xxx]

The health effects of temperature are further aggravated by air pollution (Graff Zivin and Neidell, 2013) and humidity (Barreca, 2012), both of which negatively impact health directly. Not controlling for humidity in equation 1, leads to 0.9% lower mortality rates for the US, underestimating the potential cost of climate change.

Natural disasters also lead to death. Those who were less physically strong, like children and older adults, and those who could not find help from a physically strong person, were less likely to survive the 2004 Indian Ocean Tsunami in Indonesia (Frankenberg et al., 2011).

A sub-strand of the literature looks at long term effects on human capital, and finds that climate change represents a major threat to health and education during childhood, which are likely to affect employment outcomes later in life.[xxxi]

2.4. On-the-job productivity, wages

Several studies examine how climate change affects on-the-job productivity. These papers tend to follow the approach set out in equation (1), but the level of observation differs, leading to estimation at the micro, meso, or macro level, which each measure and define worker productivity in their own way. Micro studies focus on observed individual worker performance, output or wages as the left-hand side variable.[xxxii] Studies at the sector or economy wide level typically consider output per worker, using an aggregate economic indicator such as output, value-added, or GDP, divided by reported number of workers employed.[xxxiii]

Increased temperature generally has an adverse effect on labor productivity, and this seem to hold across settings, specifications, levels of observation, and types of output. This is confirmed by a recent review of a subset of studies (Lai et al., 2023). Micro-level analysis in developing countries finds a negative relationship between productivity and temperature. In India's manufacturing sector, a 1°C increase on a hot day reduces labor productivity by 2–4% (Somanathan et al., 2021). For garment factories in India, productivity effects of relatively hot days are in the magnitude of -2 pp/+1°C for temperatures above 27°C-28°C (Adhvaryu et al., 2020). Workers' data from non-climate-controlled manufacturing firms in China suggest a U-shaped relationship: temperature is positively correlated with productivity up to 78°F (~25°C), after which productivity declines with further warming (Cai et al., 2018). Call center workers in India see a productivity decline of 1.8% for a 1°C rise over a temperature range from 21.9°C to 28.5°C (Niemela et al., 2002).

Because individual worker productivity can be hard to measure, some research focuses on the change in firm Total Factor Productivity (TFP) obtained from estimating a production function. Firm-level analysis of 500,000 Chinese manufacturing plants finds heat stress to be strongly related to economic output (Zhang et al., 2018): a day with a temperature above 90°F (32°C) lowers TFP of the average manufacturing firm by 0.56% relative to a day with a temperature between 50° -60°F (10°C-15°C), resulting in 0.45% lower output. Productivity losses tend to be larger for workers in heat-exposed industries.[xxxiv] In Chinese manufacturing, the largest losses in value added per worker on hotter summer days occur in industries where workers are highly exposed to heat while air conditioning is largely infeasible; these include ferrous metal mining (-48.7%/+1°C) and timber (-41.2%/+1°C) (Chen and Yang, 2019). Losses in agricultural TFP in China are estimated at 2.6% for every additional day with a temperature of more than 33°C during the year (Chen and Gong, 2021).

These findings are consistent with county-level payroll evidence from the US indicating that labor productivity in highly-exposed non-agricultural industries, such as utilities, mining, and manufacturing, declines by as much as 50% on a workday above 95°F (35°C), a ninefold impact relative to less exposed industries, although there seems to be adaptation when evaluating cross-county differences (Behrer and Park, 2017).[xxxv]

In indoor controlled environments, productivity tends to be similarly negatively associated with temperature, often in a non-linear, U-shaped way. A meta-analysis of indoor office, laboratory, and classroom settings finds task performance to increase until reaching a ceiling at 21°C- 22°C, with further increasing temperature from 23°C to 30°C resulting in a 9% productivity loss (Seppanen et al., 2006). Student performance among college entrants in China declined by 2.9% of a standard deviation for a 1°C increase in mean temperature of 23°C during the exam period—with a more pronounced effect for high-performing students (Graff Zivin et al., 2020). These impacts are larger than those found among students of similar age in New York (-1.60%/+1°C) (Park, 2022), possibly due to lower unobserved adaptation, like access to air conditioning.

Health is increasingly seen as an important mediating factor. When heat exceeds certain thresholds, negative physiological responses such as respiratory disease and cardiovascular strain, higher levels of fatigue and exhaustion, heat strokes, and cognitive impairment can affect body and brain functioning, which typically reduce work capacity while on-the-job (Zander et al., 2015). One adaptive response to cope with these effects is to reduce labor effort. DHS interviewers reduce their labor effort on hotter and more humid than usual days, completing 13.6% fewer interviews per hour (LoPalo, 2023). Rice harvesters in India self-report heat exhaustion, pain, signs of cardiovascular strain, during work on hot days, which caused a reduction in the number of rice bundles collected per worker – the equivalent of 5% lower hourly productivity per worker per 1°C at WBGT > 26°C (Sahu et al., 2013). Emerging evidence suggests that workers may acclimatize to heat exposure as the body may develop heat tolerance over time, which may mute productivity loss, but more research is needed to understand this relationship.[xxxvi]

An alternative response is to increase the number of rest breaks. In Indonesia, workers in deforested settings that lack natural cooling services are 8% less productive and take 44% more breaks; they are found to have a 0.14°C higher median core body temperature and experience 39% chance of moderate hyperthermia (Masuda et al., 2021). Taking more breaks was found to be the key mechanism through which productivity declined, as work effort measured by physical activity using an accelerometer showed no differences between the two groups.

These micro impact estimates provide important complementary insights to macro-level estimates. First, they suggest that the latter may underestimate the economic costs of climate change when not taking on the job productivity losses into account. Second, they present a channel through which output losses occur, formally testing a hypothesis made by early research.[xxxvii]

The primary focus on short-term effects, and limited attention for adaptation, may mean that these impacts will be smaller in the long run. Nevertheless, magnitudes of productivity losses may be substantial.[xxxviii]

2.5. Income, vulnerability among self-employed

Changing weather patterns increase vulnerability and variation in income of the self-employed, especially in agriculture, increasing the risk of poverty. The poorest populations, which typically include smallholder subsistence farmers, are likely to be hit hardest and most frequently by climate change events (Morton, 2007). Their livelihoods depend more on natural assets like land and livestock, tend to be concentrated in climate-sensitive activities, such as farming, forestry and capture fisheries, and they are more likely to live in hotter and drier locations (Nordhaus, 2006).

The rural poor in developing countries typically have limited capacity to cope with and manage the risks arising from negative income shocks, as shown by a large body of research, including shocks stemming from climate variability. For instance, households' main liquid assets hardly recovered to pre-famine levels a decade after the famine of the mid-1980s in the Horn of Africa, even though they had used multiple coping strategies. Cattle holdings were, on average, two-thirds in value terms of what they were before the famine (Dercon, 2002). Additionally, we have limited understanding of long-term adaptation in agriculture in developing countries. Existing work suggests that adaptation is often sub-optimal, both across space and time, as we discuss in Section 3.2, possibly due to poor incentives or high cost of adaptation, and more research is needed.[xxxix]

Rigorous research on the distribution of impacts – for instance across income levels or occupations – remains mostly absent for developing countries.[xl] The most advanced insights in this area are those related to reallocation and migration, which is what we turn to next.

2.6. Reallocation of labor

The impacts of climate change on labor demand, supply and productivity may in turn lead to a reallocation of labor. Climate migration has received much attention in the literature.[xli] Change in the sector of work – which may coincide with migration – has been studied less. We discuss each in turn.

2.6.1. Sectoral reallocation

Recent research, primarily conducted in India, demonstrates how agricultural productivity shocks caused by changing weather conditions can lead to a reallocation of labor from agriculture to manufacturing and services. Between 2001 and 2007, a rise of 1°C in the daily average temperature corresponded to a decrease of 7.1 percentage point in agricultural employment, an increase of 2.0 and 3.4 percentage point in manufacturing and services employment, respectively, and a 0.7 percentage point increase in district-level unemployment (Colmer, 2018). Rural households that have experienced depletion of their first borewell within the past ten years are four percentage points more likely to see their adult members engaging in non-agricultural off-farm work (Blakeslee et al., 2020).

Flexible and integrated labor markets can facilitate reallocation and expansion in the receiving sector. In more flexible local labor markets in India, an increase in the daily average temperature is linked to a 10% growth in output and a 14.6% increase in the number of contract workers in formal manufacturing firms. Conversely, in the less flexible labor markets, there was a decrease in employment, marked by a 12.9% reduction in firm output and a 14.8% decrease in the proportion of contract workers (Colmer 2018). The majority of workers who are reassigned in the less flexible labor markets transition to smaller, informal manufacturing companies.

Other research confirms that climate change may accelerate structural change. In Brazil, economic activity in localities with higher incidence of droughts during 2000-2010 shifted more rapidly towards manufacturing, where employment increased nearly 8% while agricultural employment reduced by 11% (Albert et al., 2021). Among Indian rural households whose first borewell failed, the capacity to diversify into non-agricultural employment hinged on the structure of the local economy (Blakeslee et al., 2020). Individuals were more likely to leave their agricultural jobs in villages with more and larger firms and a more industrialized rural economy.

Local demand also matters. Falling agricultural employment and productivity can lead to lower demand for labor in the non-tradeable sector through backward and forward linkages, while manufacturing employment may at the same time expand with labor becoming cheaper (Liu et al., 2023; Albert et al., 2021). Likewise, an increase in local demand can promote the shift of labor from agriculture to non-agricultural sectors in response to positive rainfall shocks, as higher incomes stimulate greater demand for local products and services. A 1-standard deviation above local average rainfall during the main growing season in rural India increased the probability of households having a primary occupation in the non-agricultural sector by 1.1 percentage point (Emerick, 2018).

The influence of climate change on structural transformation is garnering growing interest and presents a promising avenue for future research.[xlii]

2.6.2. Climate migration

Variations in climate can affect people's choices to migrate in search of employment opportunities.[xliii] Several aspects of this relationship warrant investigation.

Multiple studies observe a strong correlation between migration and rising *temperatures*. Higher temperature induces within-country migration from rural to urban areas in Mexico, as well as cross-border migration to the US (Jessoe et al., 2018; Nawrotzki et al., 2015) . An additional Harmful Degree Day – defined as a day with an increase in temperature from 32.5°C to 33.5°C – increases the probability of migrating to urban areas and to the US by 1.4% and 0.3%, respectively. In El Salvador, an extreme rise in temperature decreases agricultural productivity and total production. To compensate the loss in income and escape poverty, farmers cut back their demand for hired workers, which in turn leads to out-migration, including to the US (Ibanez et al., 2022). Heat stress is found to be strongly related to long-term migration in Pakistan, particularly for men who mostly move long distances, including abroad, while women often move within geographical areas and villages (Mueller et al., 2014).[xliv] In Indonesia, higher temperature raises the probability of permanent household migration in non- linear ways, by 0.8% when the mean temperature increases from 26°C to 27°C*,* and by 1.4% when it increases from 27°C to 28°C (Bohra-Mishra et al., 2014).

Migration is also related to decreases in *rainfall.* A one-standard-deviation decline in rainfall, signifying a negative rainfall shock compared to the long-term average, leads to a 4.5% reduction in agricultural labor in China and a 5% increase in migration to urban areas. This effect is particularly pronounced among younger individuals (Minale, 2018). In Bangladesh, the likelihood of internal migration rises when a higher percentage of households face crop failure due to rainfall (Gray and Mueller, 2012). Similarly, in Indonesia, agricultural households affected by unanticipated low rainfall are more likely to have a household member migrate to a nearby area (Kleemans, 2015; Kleemans and Magruder, 2018).

Studies examining fluctuations in both temperature and precipitation indicate that the relationship between precipitation and migration is less robust and less pronounced compared to that with heat and rising temperatures. While rainfall and flooding can prompt temporary and short-distance movement in Pakistan and Indonesia, permanent migration tends to be predominantly linked to temperature increase (Mueller et al., 2014; Bohra-Mishra et al., 2014; Kleemans, 2015).

Research on migration impact of natural disasters tend to find a strong relationship, though evidence for developing countries remains scarce. In the US, regions affected by tornadoes in the early 1900s exhibit increased net emigration, whereas areas subject to flooding experience greater inward migration, likely due to the government's reconstruction efforts in flood-prone regions, rendering them more appealing for economic activity (Boustan et al., 2012).

In a similar vein, the Dust Bowl of the 1930s in the US, characterized by severe dust storms and drought that ravaged the US Great Plains, was found to trigger substantial emigration from impacted regions, leading to decline in the local population (Hornbeck, 2012).[xlv] Migration prompted by natural disasters may mediate lower local economic growth. On average, annual economic growth fell by 0.45 percentage points in hurricane-exposed US coastal counties, of which 28% are attributed to the relocation of wealthy individuals (Strobl, 2011). Scarce evidence for developing countries indicates that international migration to OECD countries is positively related with natural disasters in the migrants' home country. However, the intensity of this relationship fluctuates depending on the nature of the disaster and the geographical region in question (Drabo and Mbaye, 2015).

Climate migration seems to accelerate urbanization up to some limit. Precipitation is positively related to urbanization in Sub-Saharan Africa (Barrios et al., 2006).[xlvi] But moisture, measured as a function of precipitation and evapotranspiration, is negatively associated with the absorption of farm workers into the urban labor force across 29 African countries, especially in cities with a strong manufacturing presence (Henderson et al., 2014).

Causal identification remains a challenge when analyzing climate migration. Impact estimates may reflect pull as well as push factors, and attribution to a single element is often impossible (Mueller et al., 2020).[xlvii] The implication for policy is that, in many instances, it may be more effective to promote overall labor market integration rather than focusing on specific groups or measures. However, there is a unique case when it comes to conflict, which is frequently overlooked in the analysis.[xlviii]

In general, climate migration tends to be seen as a coping strategy to alleviate liquidity constraints stemming from climate-related shocks (Kleemans 2015; Bazzi 2017), but at the same time frequently necessitates access to capital (Cattaneo and Peri, 2016).

3. Response to the impact of climate change on labor

Economic actors respond to the labor impact of climate change both through adaptation and mitigation. This section examines on the observed responses of firms, farms, households and workers to the first order labor impacts of climate change discussed earlier, with subsequent focus on government policy responses.[xlix]

3.1. Methods and identification

How do economic agents respond to a manifested impact of climate change on labor? The nascent literature in this area follows one of three approaches when analyzing the response of firms and workers.

A first group of studies investigates *the extent of adaptation*, regressing observed adaptive behavior on temperature. A common example is a firm’s adoption of air conditioning to improve worker productivity.

The analysis is similar to the one presented in equation (1), with the adaptation behavior as left-hand side variable.[l]

A second family of papers focuses on how adoption moderates the impact of climate on labor. In this approach adaptation enters as a right-hand side variable in equation (1) where it is interacted with the climate variable. For instance, one can study whether the adoption of AC alters the impact of temperature on worker productivity. While this does not amount to causal testing of the underlying mechanism, the obtained estimates allow assessing whether the impact of climate – in this case temperature – on worker productivity varies with adoption.[li] The same approach can be used to evaluate the adaptation capacity of specific subgroups (e.g. gender and income in the case of workers, size and profitability for firms; firms; regions; or industries).[lii]

A third approach compares the short-term impact estimates obtained from equation (1) with estimates obtained from a long-term-difference equation (which differences out short-term unobserved changes) to get an approximation for adaptation over time (see Dell et al., 2014; Hsiang, 2016). This approach can be used to evaluate if short-term impacts are offset in the long term.[liii]

These approaches suffer from some of the limitations discussed earlier, in particular that actual temperature (or other climate change variable) to which workers are exposed remain unobserved, and that the estimates are for partial equilibrium only.

How governments respond is typically assessed using the classic tools from impact evaluation. Few studies are able to report rigorous estimates based on exogenous variation (e.g. a discrete cut off, or a roll out over time).[liv] Other thorough work in this area uses panel data fixed effects estimation of the form presented in equation (1). While the policy target of interest serves as left hand-side variable, only a limited number of studies evaluate the impact of policies interventions on labor outcomes. Most studies in this field concentrate on the impact of policies on output or emissions as the left-hand side variable.

3.2. Firm, farm, household and worker response

Firms may mitigate the negative impact of higher temperature by cooling the workplace. Firm adaptation effort depends on the relative cost of adopting climate controls such as air-conditioning, passive cooling systems, or specific heat saving technology, versus the gains in output stemming from the resulting improvements in labor supply and productivity.

Some adaptation measures may therefore be less attractive for low-productivity jobs. In India, the probability of investing in climate control is substantially lower in cloth-weaving plants compared to diamond plants (Somanathan et al., 2021). Air conditioning for the average cloth-weaving firm costs nearly 23% of the total wage bill, while estimated productivity loss is about 2%–4% per 1°C rise, making the investment unattractive for low-markup firms. In contrast, high value-added diamond plants do provide air conditioning, especially to polishing units, which carry out work central to diamond quality and value.[lv]

For other technologies, benefits may exceed costs more rapidly. Energy-efficient LED lighting was reduced heat, thereby increasing worker productivity, and at the same time lowering energy costs (by almost a third), lowering the break-even period from 3.5 years to 8 months (Adhvaryu et al., 2020).[lvi]

Our understanding of how *farmers* respond to climate change impacts is growing. Rice farmers in China use a range of adaptation strategies including upscaling irrigation, reseeding, fixing and cleaning seedlings, changing crop varieties, as well as increasing the use of fertilizers and pesticides. While these measures tend to improve mean yield, only a third of farms employ these at times of flood and drought (Huang et al., 2015). In Ethiopia farmers report using increased irrigation, soil conservation to preserve moisture content, drought-tolerant crop varieties, adjusting of planting time, and planting trees (Deressa et al., 2009). Famers in Bangladesh adopted heat-tolerant rice crops, switching in the process from rain-fed to irrigation-based varieties (Moniruzzaman, 2015).[lvii] Dryer and hotter climate encouraged farmers in South

America to adopt more suitable crop varieties including squash, fruits, and vegetables (Seo and Mendelsohn, 2008).

While some of these adaptation strategies overlap, others vary by country, setting, and income group. Whether they reflect an optimal response to local conditions remains an active field of research. In China farmers managed to mitigate 9% of potential yield losses by adapting planting dates and growing-season length in response to contemporaneous changes in temperature. No such or other response is observed in the long term, suggesting suboptimal behavior (Cui and Xie, 2022). In India, hotter districts were found to adapt for temperature increases in the range of 18°C to 27°C, by adopting new agricultural practices and switching to heat-tolerant crops, resulting in lower yield losses than colder districts that faced the same increase.[lviii] But for higher temperature rises (>30°C), their losses were the same as in cold districts, suggesting non-optimal adoption (Taraz, 2018).

This is broadly consistent with findings in high-income countries. In the US temperature affects maize yields in hot (Southern) and cool (Northern) states almost identically and there is little variation in the temperature-crop relationship across time, despite technological advances in farm-level adaptation for warmer climate (Schlenker and Roberts, 2009). In France, equal short- and long-term losses in wheat yields (10% and 7%, respectively), related to a 2°C warming also indicated limited adaptation over time (Merel and Gammans, 2021).

Restricted information, incomplete insurance, lack of access to extension services, and low adoption of technology itself have been named as barriers to optimal adaptation (Huang et al., 2015; Karlan et al., 2014; Suri and Udry, 2022).

Beyond the farm-level response, rural *households and workers* are found to use multiple strategies to reduce exposure and mitigate impact of climate shocks. These include common individual and collective strategies to reduce the impact of income shocks, like diversification, precautionary savings, liquidation of assets, and risk-sharing (Dercon, 2002). Among Eastern and Southern African households, about a third adopted alternative forms of employment and one in six reduced consumption to adapt to climate shocks. In Ethiopia and Tanzania over 50% of households used savings or borrowing as a primary response to climate shocks. In Kenya, two third sold livestock as part of changing farming practices (Rahut et al., 2021).[lix] A large literature on income shocks shows that, despite the variety of risk-coping strategies they adopt, rural households do not manage to completely insure against income loss.[lx] How households and workers can insure themselves against climate related shocks is receiving increased attention, and we discuss some new directions as part of social protection policies below.

3.3. Government policy response

A comprehensive overview of policies designed and implemented in response to climate change is beyond the scope of this paper. Our main interest is to what extent these policies focus on, or take into account, labor outcomes. Our examination of the relevant literature reveals two issues. First, evaluations of general climate change interventions seldom include an assessment of their labor impact. Second, climate change policies that target labor remain understudied. We discuss each in turn.

3.3.1. General climate change policies and their impact on labor

A wide range of policies aim to address challenges related to climate change. It is a very broad set; even for the highest impact is observed: from mitigation policies like fossil fuel subsidy reform, over carbon pricing, alternative power generation, change in land use, and altered transport policies, to adaptation policies like the use of increased crop variety, disaster preparedness and adaptive social protection. Table A1 in Appendix 1 provides examples of policies that have been evaluated. These appraisals pay virtually no attention to the impact on labor. On the rare occasion when they do, they tend to focus on employment, showing sizeable – typically short-term – impacts, and neglect potential effects on other labor outcomes.

As an illustration, consider the example of carbon pricing, which is seen as an attractive policy lever to bring down carbon emissions, reduce global warming, and accelerate the transition to a low carbon economy.[lxi] A simulation for US manufacturing industries finds that a 1% increase in the energy price associated with carbon tax (resulting in $15/ton carbon) reduces output in the short run by as much as 5%, particularly in energy-intensive sectors, like iron, steel and aluminum (Aldy and Pizer, 2015). Although the study extensively covers the impact on output, it neglects the impact on labor. Research in this strand typically concentrates on the policy's impact on economic output and emissions. But there is much to be gained from examining the labor-related consequences. One study, exploiting exogenous variation in eligibility for carbon tax discount across a panel of UK manufacturing firms, finds no causal evidence of policy impact on plant-level employment, and this result holds across differences in firm size, energy intensity, or trade intensity (Martin et al., 2014). In contrast, an economy wide simulation study for the US between 1976 and 2007 finds a sizeable labor impact of higher energy prices in the short term, including a negative employment effect between -0.10% to -0.16% (Deschenes, 2012).[lxii] These short-term impacts differ among sectors, with agriculture and transportation experiencing the largest employment losses, with estimated cross-elasticities of -0.43% and -0.29%, respectively.[lxiii] A study for British Columbia finds that annual employment rose by 0.74% over the subsequent 6 years, compared to the rest of Canada, when *unilaterally* introducing a state level revenue-neutral carbon tax in 2008 (Yamazaki, 2017). This masks large heterogeneity across industries with employment falling in emission-intensive and trade-exposed industries but rising in services.[lxiv] Impact evaluation of a $40/ton CO_2 carbon tax for a 30% emission coverage in Europe (EU+ countries) find positive, but generally not statistically significant, effects on employment, either immediately or in the subsequent 5 years of policy implementation (Metcalf and Stock, 2020).

Studies evaluating employment effects for developing countries remain scarce. A CGE model for the transport sector in Malaysia suggests that carbon tax leads to a fall in employment across all subsectors – echoing the negative effect on sectoral output, demand, and investment – as factors of production shift to less energy-intensive, more labor-intensive sectors in the economy (Solaymani et al., 2015). A recent IMF simulation for manufacturing in Asia and the Pacific utilizes national I/O tables to estimate the potential short-term impact of a $25/ton carbon tax (Dabla-Norris et al., 2021). Sectors that rely on carbon-intensive inputs, typically the downstream, extractive and energy-producing industries, are most affected in terms of output and employment. The amount of projected job loss is primarily driven by the industry's energy dependence and share of employment. This varies substantially across countries. In Malaysia the largest expected job losses are concentrated in electrical and electronics manufacturing while in Mongolia the vast majority projected job losses are in wood and paper manufacturing.

3.3.2. Labor targeting climate change policies

Our review of the literature points to six potential policies to target the impact of climate change on labor. We refer to these as: green jobs, green skills, labor-oriented adaptation, flexible labor regulation, labor market integration, and social protection. As shown in Table 1, each of these relate to one or more of the above discussed potential labor impacts of climate change. In depth or formal evaluation of these policies has so far remained limited. We discuss each in turn.

Table 1. Labor targeting climate change policies

Impact of climate change on labor	Labor oriented policy response H
Demand for labor	Green jobs
Supply of labor, time use	Labor-oriented adaptation, regulation for flexible work
Productivity	Labor-oriented adaptation, regulation for flexible work
Self-employed income, vulnerability, poverty	Green jobs, social protection
Reallocation of labor	Labor market integration, social protection
Skills and human capital	Green skills, social protection, education and health policies

Policies that promote "green jobs" aim to increase net labor demand while transitioning to a low carbon economy.[lxv] Although comparing the employment impact of green employment policies remains relatively rare, a small literature is emerging. Table 2 provides an overview of key studies in this area. Comparison of impact across studies is complicated by the use of different measures and methods. The emerging work on energy transition, predominantly focusing on high-income countries, provides an illustration. One study finds that an additional state-level green policy, like renewable portfolio standards and energy efficiency resource standards, is associated with 1% additional green jobs on average across 361 metropolitan areas in the US (Yi, 2013). These results corroborate the findings from simulation-based studies that dominate this literature. A multi-regional I/O analysis of the transformation of the EU energy sector over the period 1995–2009 estimates a net employment effect of +0.2.4%, an equivalent of 530,000 jobs by 2009, with one-third attributable to spillovers between EU countries, i.e. employment generated in one country due to changes in another (Markandya et al., 2016). Another EU study finds that substantial job creation can be realized in more flexible labor markets (Blazejczak et al., 2014). A simulation study for the US power sector suggests that implementing more aggressive energy efficiency measures and renewable energy standards can create over 4 million FTE green job-years by 2030, while clean nuclear energy and a rise in carbon capture and storage (CCS) to 25% and 10% of total energy generation, respectively, can create an additional 500,000 job-years (Wei et al., 2010). Since green energy tend to be more labor-intensive than high-carbon, these sectors generate more jobs for a given dollar invested. In the US, a $1 million invested in fossil fuels is expected to generate 2.65 FTE jobs versus 7.49–7.72 FTE jobs when invested in green energy, such as renewables or energy efficiency (Garrett-Peltier, 2017).

Table 2. Examples of expected impact of decarbonization policies on the demand for labor

Policy	Expected impact	Country or region	Method	Reference
State-level green policy	1% more green jobs	US	Historical data	Yi (2013)
Regional-level energy shift	0.24% increase in employment	EU	Simulation	Markandya et al. (2016)
Energy efficiency measures and renewable energy targets	4 million+ green job-years by 2030	US	Simulation	Wei et al. (2010)
Investment in renewables and energy efficiency	Around 5 more FTE jobs compared to similar investment in fossil fuels	US	Simulation	Garrett-Peltier, (2017)

State-level green policy refers to market-based tools that provide support for renewable energy and energy efficiency. Energy shift refers to a change from carbon intensive sources toward gas and renewables.

The new jobs that come with the transition to low carbon may require new skills, often referred to as *green skills*. There is, by our knowledge, very little rigorous evaluation in this area using historical data. One US study finds that changes in environmental regulation are positively related to demand for green skills, in particular for technical and engineering tasks (Vona et al., 2018). [lxvi]

Cooling technology in the workplace is an important example of *labor-oriented adaptation* that may improve worker productivity and labor supply, as well as worker well-being. As mentioned previously, firm adaptation may be less likely for low-productivity jobs (Somanathan et al., 2021). Government subsidies can be beneficial in situations where a change in behavior is considered desirable but faces obstacles, for instance when the cost of early adoption is high but anticipated to fall substantially over time, potentially due to increased demand (Stern, 2022).

Policy makers have been motivated to introduce regulation regarding *occupational health and heat management to protect workers* from heat-related stress. Preventative measures, such as frequent rest breaks, and hydration and high-sodium intake, can protect workers from heat-related illness and work accidents. These regulations are unlikely to be followed in informal firms and settings with weak enforcement. In China's manufacturing industries protective measures knew limited implementation by private firms during periods of elevated temperature (Zhang et al., 2018).

Labor regulation for flexible working may provide an alternative policy. Optimized working hours allow firms and workers to flexibly adjust work schedules to hot temperatures (Connolly, 2018). In one example workers can choose to operate more on cooler days or cooler hours within a day. In another approach, workers decide their days off, relaxing the "consecutive vacation days" requirements in some sectors; this can also reduce absenteeism. Increased flexibility is particularly attractive for those with dual job holdings, for instance working in agriculture while having a second job in trade, as they tend to adjust working hours toward less exposed activities during extreme temperatures (Li and Pan, 2020; Huang et al., 2020; Branco and Feres, 2021).

Labor market integration increases labor mobility across the economy, which in turn facilitates the reallocation of labor. In India, reallocation in response to increased temperature takes place primarily *within* districts (Colmer, 2018; Blakeslee et al., 2020).[lxvii] In other settings, integration with wider labor markets is found to stimulate climate-induced migration within and across regions, within the country, and internationally (see, for example, Bohra-Mishra et al. (2014), Mueller et al. (2014), Jessoe et al. (2018), Kleemans and Magruder (2018), Ibanez et al. (2022)).[lxviii]

Social protection can help reduce vulnerability and smoothen transition. One active area of research is shock-responsive social protection. Experimental evidence from Nicaragua suggests that conditional cash transfers combined with vocational training or a productive investment grant can help households exposed to weather variability smoothen their consumption and diversify their economic activities (Macours et al., 2022). Other research focuses on anticipatory crisis financing. Findings from a recent large-scale evaluation of immediate cash transfers during the 2020 monsoon floods in Bangladesh show that *timely* and *quick* release of cash support leads to more effective evacuation, better child food consumption outcomes, and less costly borrowing in the aftermath of the floods (Pople et al., 2021).

4. Ways forward

This paper aims to stimulate research related to the impact of climate change on labor. A better understanding of this impact is needed for at least three reasons. First, much like the increased attention for other primary factors of production, such as land and finance, a better grasp of the role of labor will inform policies that aim to promote green growth and facilitate the transition to zero carbon.[lxix] Secondly, labor remains one of the key channels through which climate change impacts individuals' livelihoods, affecting both their income from employment and their opportunities for work. Recognizing these effects can guide the development of policies aimed at poverty reduction and help steer clear of strategies that exacerbate poverty. Thirdly, the shift toward low carbon requires political, and thus citizen support. Ignoring the influence of climate change on labor could undermine such backing; acknowledging it has the potential to bolster it.

While evidence is emerging across the five areas of labor impact that we identified, its availability remains constrained, particularly for developing countries. Four observations stand out from reviewing the evidence, for which summary is visualized in Table A.2 in Appendix 2.

To begin with, there exists at least some evidence pertaining each of the different labor themes. In certain instances, this evidence originates predominantly from research conducted in high income countries, notably the US. Even so, it frequently serves as an initial reference for subsequent studies, offering valuable insights into both research methods and the expected scale of the relationships under investigation, providing an empirical benchmark. Recent efforts have been increasingly directed towards the study of developing countries. Secondly, changes in temperature have garnered the greatest amount of scrutiny, with changes in precipitation ranking second in terms of attention. Other climate change events such as rising sea levels, tropical cyclones, and drought, have received considerably less concentrated effort. One contributing factor to this disparity may be the relatively rare occurrence of these events, while the scarcity of high-quality data also plays a part. Thirdly, certain geographical regions are characterized by a dearth of available evidence. This holds true for low-income countries in general, and specifically for Sub-Saharan Africa, as well as the Middle East.[lxx] Fourthly, even though we maintained our emphasis on the highest-quality evidence throughout our review, there are several limitations with the existing analysis. The omission of adaptation in most estimations imply that the majority of estimates reflect short term impact; they also typically focus on partial equilibrium effects, and primarily are about the influence of past, already occurred events. As a result, these estimates are prone to bias when it comes to the long term. Ongoing efforts to address these shortcomings involve conducting economy wide analysis, and more precise forecasting future of climate change events, both of which remain challenging. Of particular interest is the research examining how climate change could expedite structural transformation. Essential is the work that incorporates adaptation, typically using now established methods like explicitly modelling its adoption, examining how it moderates the estimated impacts of climate events, or comparing short term impacts with those of the long term. Emerging evidence suggests that adaptation is frequently suboptimal, and we currently have limited understanding why this is the case.

In the realm of government policy much remains to be done. The assessment of general policy interventions often overlooks their impact on labor. Formal evaluation of any of the six labor-targeting policies that we identified – green jobs, green skills, labor-oriented adaptation, flexible work regulation, labor market integration, and social protection – remains scarce overall, and in particular for developing countries.

Based on these observations, we see three promising avenues for future research. A first route is to deepen research in areas where we have an initial understanding. Additional effort is required to incorporate adaptation, utilizing either existing methodologies or developing new ones. Conducting more causal analysis of historical data, whenever feasible, can further enrich our understanding. Sector specific examination serves as a solid starting point, and can be further enriched by studying impact beyond the primary activity of interest, including an investigation of both backward and forward linkages. This will serve as both a supplement to and a source of information for approaches examining economy wide effects, which remain sensitive to their underlying assumptions. Further progress can also be made in future-oriented analysis, with two avenues of work opening up. First, research comparing and integrating historical and simulation analyses would significantly enhance our knowledge base. Forward-looking projections of the likelihood of climate events have become more accurate, thanks to insights from science. Simultaneously, there has been a substantial increase in research devoted to estimating impact through historical data. Work that bridges insights from these two traditions, while considering anticipated adaptation, would be highly valuable. Second, a newer strand of work takes into account social adaptive behavior at scale, further extending the type of socioeconomic variables that are being considered, which is a promising way forward. Society wide behavior is hard to predict, and much can be gained from theoretical work, which remains limited in this area. Recent efforts underline how theory can push our understanding, for instance by recognizing endogenous preferences, the role of technology, and changing consumption patterns society wide (Mattauch et al., 2018; Besley and Persson, 2020; van der Ploeg and Venables, 2022).

Secondly, in the few themes where we have advanced evidence, replication and comparison are needed. This will help us better understand the generalizability of the results, or, failing that, the possible aspects of context that matter. Similar lessons can be drawn for evaluation of government policy. Greater utilization of evaluations examining the impact of general climate change policies on labor, along with the replication of labor-targeting climate change policies, would enable a systematic comparison of their economic and social impacts. This would help determine the relative effectiveness of these policies and enable more informed policy making.

Third, themes for which evidence is lacking warrant a thorough assessment to identify the most fundamental and pressing questions that need addressing. This process will, in turn, highlight the need for improved data.

We conclude this review with a more optimistic outlook than when we began. While there is still much work ahead, clear pathways have emerged. Combined, these research and policy making efforts will help determine the optimal paths for achieving an equitable transition to a low-carbon economy.

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Appendix 1: Climate change policies

Many of the existing policy responses worldwide primarily aim to reduce emissions and their negative impacts, but they rarely explicitly target labor outcomes. Table A1 presents examples of key climate change policy interventions that have undergone evaluation.[lxxi]

Table A1. Examples of general climate change policy interventions

Policy area	Example of intervention	Reference
Mitigation		
Carbon price	. Carbon tax and emission trading system	World Bank, IPCC (2014)
Fossil fuel subsidy reform	. Reduce fossil fuel subsidy	OECD (2018), IPCC (2014)
Power generation	. Shift from coal to renewables using pricing . Supporting governments to transit out of coal and develop alternatives to diesel	Lo (2014), World Bank Scaling Solar
Agriculture, forestry, land use	. Payment for ecosystem services	Jayachandran et al. (2017), Mohebalian and Aguilar (2018)
Transport and urban	. Infrastructure and urban design . Low-carbon vehicles and high-volume public transport . R&D and deployment of energy efficient technologies	New Climate Economy (2016), IPCC (2014)
End use	. Nudges to encourage use of more efficient appliances . Development of evidence on what works in reducing traditional biomass use . Energy efficiency products and standards	Adhvaryu et al. (2020), Leach and Oduro (2015), Mobarak (2012)
Adaptation		
Crop varieties	. New high yield crop varieties tolerant to pests/diseases and drought/flood/salinity	Dar et al. (2013)
Disaster preparedness	. Early warning systems, enhanced weather and climate services, flood prevention and protection, preventative health for climate sensitive diseases	Kuik et al. (2016)
Adaptive social protection	. Shock-responsive adaptation . Alignment with humanitarian systems	Conway and Schipper (2011)

Appendix 2: Mapping the evidence

Table A2 provides a stylized overview visualizing what evidence exists on the impact of climate change on labor.

Table A2. Visualization of existing evidence on climate impacts on labor, globally

	Climate related events				
Area of impact	Temperature and heat extremes	precipitation	Sea level rise and flooding	Tropical cyclones and storms	Drought
Economy wide	E	E	N	E	N
Agriculture	E	E	N	E	E
Industry and services	E	E	N	E	N
Demand for labor, by sector					
Agriculture	E	E	N	N	E
Industry outside agriculture	E	N	N	N	N
Energy*	E	-	-	-	-
Service	N	N	N	N	N
Labor supply and time allocation	E	E	N	N	N
Worker productivity on-the-job	E	N	N	N	N
Income, vulnerability among self-employed	N	N	N	N	N
Reallocation of labor					
Sectoral reallocation	E	E	N	N	N
Climate migration	E	E	E	N	N

E= Evidence across context, mostly from historical analysis or from simulation; **N**= No or very limited quantitative evidence;
* Work on Energy mostly concentrates on the impact of green transition rather than climate change events themselves.

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[i] Some estimates suggest that a 1°C warmer year reduces income per capita by 1.4% on average, with substantial variation across countries, and greater impact in developing countries (Dell et al., 2012). Changes in precipitation have large impact for some countries, especially in Sub-Sahara Africa, but not all (Barrios et al., 2010). Extreme weather events, such as cyclones, also lead to substantial economic losses, especially in countries where they are less frequent (Hsiang and Jina, 2014).

[ii] The poor typically depend more on income from agriculture, which is affected by weather events, and tend to be more exposed to increased heat and floods (Hallegatte et al., 2016). They also have less access to effective management and coping mechanisms. Vulnerable groups include ethnic minorities, people with disability, and refugees.

[iii] This is sometimes referred to as the High Dimensional Fixed Effects (HDFE) approach in the climate change literature. See Lai et al. (2023), who provide a review of a specific subset of studies on temperature and worker productivity following a similar approach.

[iv] Using micro-level worker, firm or household data, or meso- or macro-level sector, region or country data.

[v] The climate change literature increasingly uses temperature bins, also to allow for possible nonlinearity in the relationship (Dell et al., 2014).

[vi] An extreme example is when workers operate in AC environment without this being registered.

[vii] Key is the 'iterated expectations' assumption that no unanticipated changes take place in expectations, which is unsatisfactory, lays at the base of the models' fragility, and makes them "least performing when they are most needed". See Mizon and Hendry (2014) for a discussion.

[viii] Omitted climatic and atmospheric variables that may have a direct or joint impact on the outcome, like precipitation, humidity, and ambient air pollution in the case of temperature, may bias estimates or render them less precise.

[ix] In a companion study we carried out an overview study focusing on the Middle East and North Africa region, where both COP 27 and COP 28 take place. The draft results are available upon request.

[x] An additional 1-day cumulative exposure to temperatures above 33°C during a single year is found to have a negative short-run impact of 4.4% on agricultural yield across counties in China (Chen and Gong, 2021). Annual growth rate of rice yields declined by up to 30.6% across farms in Asia, primarily due to the negative impact of higher minimum temperature on its vegetative and ripening phases (Welch et al., 2010). Higher temperature reduces output for major crops in Sub-Saharan Africa, with expected reductions of 22% for maize, 17% for sorghum, 17% for millet, 18% for groundnut, and 8% for maize by midcentury. Countries with the highest average yields are expected to encounter the largest losses (Schlenker and Lobell, 2010). Earlier draft work for Indian districts over a 40-year period finds major crop yields to decline by 9.5 percentage points if mean temperature of a single day shifts from 29°C to 31°C, which is estimated to lead to 5%–9% decreases by mid-century (Guiteras, 2009).

[xi] In Indonesia, district rice output increased by 0.4% for a 10% increase in rainfall (Levine and Yang, 2014). In the US, an additional week of drought reduced corn and soybean yields by up to 1.2% in dryland counties and 0.5% in irrigated counties—though the magnitudes are region-specific (Kuwayama et al., 2019).

[xii] In the Caribbean, one-standard deviation increase in exposure is associated with a 1.8% decline in output in agriculture, hunting, and fishing (Hsiang, 2010).

[xiii] The drop in rural employment would be the equivalent of an accumulated 236,094 fewer employed individuals by 2075 under the Representative Concentration Pathways (RCP) medium emissions scenario (Jessoe et al., 2018). Representative Concentration Pathways (RCPs) are scenarios used by Intergovernmental Panel on Climate Change (IPCC) for climate modelling and research. Each pathway describes a particular – and possible – climate future depending on how much of greenhouse gases can be emitted in the coming years. Generally, the RCP 8.5 is considered the worst-case scenario (~5°C increase by 2100 relative to pre-industrial baseline), while RCPs below that are considered more stringent in terms of climate mitigation efforts required—the most stringent being RCP 1.9 (~1.5°C, adopted by the Paris Agreement) and RCP 2.6.

[xiv] Heat exposed industries here include construction, mining, and manufacturing with outdoor work activity or heat generating indoor production processes that do not use climate controls.

[xv] India is exposed to almost 10% of the world's cyclones.

[xvi] The literature distinguishes between intensive margin, which is characterized by increased electricity use (e.g. AC, heaters) and extensive margin, which includes longer-run investments in cooling/heating systems installation, energy-efficient homes, irrigation, for instance (Carleton and Hsiang, 2016; Auffhammer and Mansur, 2014).

[xvii] Evidence for the US demonstrates how energy consumption is highest on cold and hot days, and attenuates mortality impacts of temperature extremes. US annual residential energy consumption is expected to grow by some 15% to 30% by the end of century (Deschenes and Greenstone, 2011), and up to 55% in some states such as California (Auffhammer and Aroonruengsawat, 2011).

[xviii] Employment outside the energy sector may also fall during the transition to a zero-carbon economy. For instance, derived labor demand in energy-intensive industrial sectors may fall when increased energy prices lower primary demand for energy (Pestel, 2019; Deschenes, 2012; Kahn and Mansur, 2013).

[xix] For instance, CGE models that account for induced employment changes outside the supply chain of interest are 43% more likely to report lower net employment effects (Stavropoulos and Burger, 2020).

[xx] For a discussion on how to improve IAM models, see for instance Dietz and Stern (2015), who lay out the method's shortcomings and conclude that improved modeling calls for strong controls. The models' shortcomings lie in what are otherwise their strengths: they are good at addressing small perturbations (which is useful when marginal change is the focus of attention). Underlying assumptions that abstract from the endogeneity of growth, convexity of damage, and the valuation of tail risk make the models ill equipped to study structural shifts that may be required in the case of climate change.

[xxi] Wet bulb globe temperature (WBGT) is a commonly used measure for heat exposure on humans, which takes into account temperature, humidity, wind speed, sun angle, and radiation.

[xxii] For other evidence, including from simulation studies, see Zander et al. (2015), Zhao et al. (2021).

[xxiii] The study analyzes 9,000 DHS interviewers across 46 countries.

[xxiv] Years of elevated temperature over the period 1989-2011 reduce the probability of working in agriculture as primary employment, with workers with a secondary occupation engaging more in non-farm work that is less exposed to heat, even though this shift comes with lower earnings on average (Li and Pan, 2020). The projected increase in mean temperature in China as a whole is associated with an expected shift in labor supply from farm to off-farm work of by 9%–36% by 2100 depending on the RCP climate scenario, corresponding to an increase in off-farm labor supply by about 44.1 million workers, when not taking possible adaptation into account (Huang et al., 2020).

[xxv] Within-day substitution happens mostly toward the end of the day. Workers do not shift activities across days. The study uses worker data from time use surveys, linked to weather data over the 2003–2006 period.

[xxvi] They reshuffle interview activity to start their work earlier in the morning when temperature is lower, to keep the number of interviews per day unchanged, in accordance with supervisor's instructions (and under a fixed daily wage contract) (LoPalo, 2023).

[xxvii] Suggestive evidence for China shows that higher temperature is associated with a larger decline in time allocated to farm work and a smaller increase in time allocated to off-farm work, for women relative to men (Huang et al., 2020). During hotter temperature, female workers are relatively more likely to reduce their working hours, have a lower probability of being employed in an agricultural job, and face reduced wages (Li and Pan, 2020).

[xxviii] This is also relevant for forward-looking studies. A cross-country simulation predicts a loss of about 2%-4% of total working hours worldwide by 2030 due to high temperatures, equivalent to 80 million to 136 million full-time jobs – depending on the climate scenario and the amount of agricultural and construction work assumed to be carried out in the shade (Kjellstrom et al. 2019).

[xxix] This assumes a business-as-usual climate scenario. Findings are similar when controlling for humidity and using residential energy consumption for air conditioning as a measure of adaptation, though impacts vary across distribution and region (Barreca, 2012).

[xxx] Impacts are observed across different age groups, including working adults, children and elderly. Children and elderly are particularly vulnerable. Children at a young age have lower capacity to dissipate heat and are more vulnerable to climate-induced infections and vector-borne disease, which are among the primary reasons for child mortality in low- and middle-income economies (Hanna and Oliva, 2016). In the US, mortality impacts at the hottest and coldest days are more pronounced for people aged 65+ (Deschenes and Greenstone, 2011).

[xxxi] Young children are found to be at heightened risk of ill health and low birth weight due to extreme temperature in the US and elsewhere (Deschenes et al., 2009; Banerjee and Maharaj, 2020). In Ecuador, a 1°C higher-than-average in-utero temperature exposure is found to be related to 0.7% lower earnings for adult males and females working in the formal sector (Fishman et al., 2019). Women who experienced more rainfall as infants during 1953–1974 in Indonesia are taller, completed more schooling, and are more likely to be wealthier (Maccini and Yang, 2009). Infants in Ethiopia who lived through the peak of the 1984 drought were significantly shorter 20 years later, compared to those unaffected by the draught, leading to 5% lower annual income over the course of adulthood (Dercon and Porter, 2014). Where climate change decreases food security, it may result in malnutrition, which may lead to adverse outcomes in later life, including in terms of education achieved, earnings and labor supply (see, for example, Smith (2009), Gertler et al. (2014), Attanasio (2015)). Climate change may also impact education directly. In China total test score on college entrance examination declined by 0.68% for a 1 standard deviation increase in temperature during the exam period (Graff Zivin et al., 2020). Student performance on a high-stakes assessment declined at hot temperature during exam day in the largest public school district in the US (Park, 2022). Interestingly school air-conditioning can offset these effects (Park et al., 2020). Whether these falls in outcomes are scarring or can be compensated with later catch up is currently unknown. Evidence from an earthquake in Pakistan also suggests that among affected children those with educated mothers catch up and close the deficits (Andrabi et al., 2021).

[xxxii] For example, Somanathan et al. (2021) gather daily data on meters of cloth woven by factory workers. Cai et al. (2018) use number of paper cups produced per factory worker per day.

[xxxiii] A common approach is to use production data from national accounts divided by country population to arrive at per capita value-added, aggregated at the industry level using the International Standard Industrial Classification (ISIC) (cf. Hsiang, 2010).

[xxxiv] To assess heterogeneity using equation (1), studies interact a dummy variable for highly exposed industries with the temperature variable or carry out a subsample analysis by industry.

[xxxv] The impact of an additional hot day above 95°F (35°C) for relatively hot regions corresponds to about a third of losses in colder or milder regions in the US in terms of labor productivity during a hotter year.

[xxxvi] The impact of days with maximum temperature over 100°F (38°C) among US workers is smaller in August – typically a hot month– compared to June, suggesting short-term worker acclimatization (Graff Zivin and Neidell, 2014).

[xxxvii] Hsiang (2010) conjectured that economy-wide output loss in the magnitude of 2.5% for +1°C in the Caribbean is more likely than not driven by labor productivity losses.

[xxxviii] Future global economic heat related productivity losses have been estimated to be in the range of 0.44% (RCP 2.6) to 2.9% (RCP 8.5) of global GDP in 2100, after accounting for adaptation (Zhao et al., 2021).

[xxxix] Changes in agricultural outcomes over time in response to weather variability are modest when compared with, for example, the strong long-term patterns of adaptation in health (Carleton and Hsiang, 2016).

[xl] Cai et al. (2018) provide an exception. Distributional impacts across levels of income, gender or ethnicity have received some, but limited, attention in high income countries (Hsiang and Narita, 2012; Hsiang and Jina, 2014).

[xli] Climate migration refers to people changing location in response to the impacts of climate change.

[xlii] Barrett et al. (2023) provide a conceptual review of structural transformation and climate.

[xliii] Climate migration research tends to focus on permanent migration; seasonal or circular migration, or commuting time receive much less attention.

[xliv] The study combines 21-year longitudinal survey data with satellite measurements of climate variability.

[xlv] Because of the Great Depression, access to capital was limited and growth in local manufacturing weak, resulting in population decline being the main short- and long-term adjustment of the local economy.

[xlvi] A 1% reduction in precipitation levels is associated with a 0.45% rise in urbanization. Similar evidence exists for Sub-Saharan Africa during 1960-2000 with climate migration increasing urban labor supply, which both strengthened agglomeration economies and reduced wages (Marchiori et al., 2012).

[xlvii] In contrast to other labor themes, the climate migration literature has paid considerable attention to co-determinants of climate migration, including historical local climate variability, farm income, wealth, and agricultural yield, as well household member's education (Saldana-Zorrilla and Sandberg, 2009; Feng et al., 2012; Mueller et al., 2014; Bohra-Mishra et al., 2014.).

[xlviii] While beyond the scope of this paper, it is useful to consider the role of conflict. Estimates of the impact of climate on migration that do not control for conflict may be mis-interpreted and misinform policy design. Temperature rise is found to cause conflict, which in turn affects economic performance and migration. The literature finds a strong relationship between climate change and civil war (Burke et al. 2009), intergroup conflict (Hsiang et al., 2013) and within country violence and conflict, among others due to drought (Maystadt and Ecker 2014) and water scarcity (Unfried et al. 2022). Conflict also causes migration, especially in low-income countries (Ibanez and Velez, 2008), affects labor supply and wages (Minoiu and Shemyakina, 2014) and physical and human capital (health, educational attainment) (Serneels and Verpoorten, 2015). It disrupts markets and is a key obstacle for economic development and growth.

[xlix] The distinction between the impact of climate change and the response to it is to some extent semantic. Workers may respond to higher temperature by reducing their labor supply, which we discussed under 'impact'. Impacts may also be related: reductions in labor supply may lead to sector relocation or migration.

[l] For example, to assess the effectiveness of firms' climate-control investments, Somanathan et al. (2021) use an indicator reflecting adoption of air-conditioning as left-hand side variable.

[li] Comparing impact across adopter and non-adopter subsamples serves the same objective (cf Somanathan et al., 2021).

[lii] For example, Chen and Yang (2019) interact a dummy for high-temperature regions with temperature variables to assess if value added per worker varies by climatic region. Graff Zivin and Neidell (2014) use this approach to test for adaptation in labor supply response across workers in the hottest and coldest US counties.

[liii] This approach has been used to study adaptation in the context of cognitive performance (Graff Zivin et al., 2018), US corn productivity (Burke and Emerick, 2016), economic growth (Dell et al., 2012). The estimation typically follows the following specification:

$$\Delta Y_{ij(t_2-t_1)} = \beta \Delta T^{e}_{ij(t_2-t_1)} + \Delta C^{e}_{ij(t_2-t_1)} \Gamma + \Delta X_{ij(t_2-t_1)} \Pi + \gamma_{j(t_2-t_1)} + \Delta \varepsilon_{ij(t_2-t_1)} \qquad (2)$$

[liv] The scarcity of rigorous studies is related to the limited availability of high-quality data, as well as to the relatively late engagement of economics with empirical analysis of climate change (Oswald and Stern, 2019).

[lv] AC adoption can also improve cognitive productivity. In US schools adopting air conditioning, high school students obtained higher standardized test scores, reducing the impact of high temperature (Park et al., 2020).

[lvi] The energy-efficient LED lighting attenuates 80% of the productivity effects of hot days by reducing heat dissipation, compared to conventional light bulbs.

[lvii] Whether this adaptive response is optimal remains unclear. While a shift towards large-scale irrigation in US counties with access to aquifer grounder water established drought resistance, changes in land allocation toward high-value water-intensive crop increased drought sensitivity (Hornbeck and Keskin, 2014).

[lviii] Crops observed were rice, wheat, maize, sugarcane, groundnut and sorghum.

[lix] A descriptive World Bank study reports similar findings for MENA (Adoho and Wodon 2014).

[lx] See, for example, Coate and Ravallion (1993), Udry (1994), Townsend (1994), and Ambrus et al. (2014).

[lxi] Carbon pricing puts an explicit price on carbon to curb negative externalities and achieve a social optimum. It refers to a collection of approaches with carbon taxes and cap-and-trade systems as the most common (see Auffhammer et al. (2016), for a general discussion on carbon pricing). Carbon pricing is adopted more in high than middle- and low-income countries, See carbonpricingdashboard.worldbank.org. for an overview of established and ongoing carbon pricing initiatives worldwide.

[lxii] This reflects the cross elasticity of Full Time Equivalent (FTE) with respect to real electricity prices. This analysis, like most US analysis, uses within-state, year-to-year variation in US electricity prices, as a proxy for higher energy prices resulting from carbon pricing policy, based on the reasoning that electricity prices are a first-order impact channel of climate policy on the labor market. While this is a well-reasoned approach, one cannot exclude the potential for omitted variable bias, for instance, if unobservables influence changes over time in both within-state electricity prices and labor outcomes.

[lxiii] To put the aggregate estimates in context, a forward-looking analysis vis-a-vis the predicted US national carbon emission targets indicates a short-term loss of 460,000 FTE employment, or 0.6% of total employment, if electricity prices rise by 4%. These estimates do not account for the effects of compensatory measures that may offset the negative impact on labor demand.

[lxiv] The $10/ton CO2 tax led to -38% employment in chemical manufacturing, -25% in electric power generation, +18% in health care services, and +15% in retail trade.

[lxv] A green job can be defined from an output-based or a process-based perspective, where the former focuses on environmental goods and services while the latter concentrates on production processes (US Bureau of Labor Statistics). The use of multiple definitions for green jobs complicates comparison across studies (Deschenes, 2013).

[lxvi] The paper identifies impact by exploiting geographical variation in regulatory stringency across the US. An ILO simulation that assesses the skills for green transition in 32 countries worldwide estimates that some 2 million workers may require 're-skilling' for different occupations, and close to 20 million require 'upskilling' for new jobs, across low-, medium-, and high-skilled occupations (ILO, 2019). Changes in required skills – whether by greening existing jobs or developing new "green" jobs – are concentrated in renewable energy, environmental goods and services, and construction; effects of the low-carbon transition are less certain for other sectors. Gender disparity is expected to persist, with most job creation and reallocation likely to occur in men-dominated mid-skill occupations.

[lxvii] The expansion of road networks can have a significant impact. It enabled the integration of local labor markets in post-liberalization India (Allen and Atkin, 2022).

[lxviii] Improved labor mobility can also improve general wellbeing, including health. Of total life expectancy gains in the US over the last 30 years, 4%–7% are attributable to the geographical mobility of the US population from the cold Northeast to the warm Southeast regions (Deschenes and Moretti, 2009).

[lxix] For a discussion on climate change and land and the challenges for banking and the financial sector at large, see IPCC (2019) and Campiglio et al. (2018), respectively.

[lxx] Draft results of a companion study that takes stock of existing evidence for the Middle East and North Africa are available upon request.

[lxxi] The overview builds on one possible categorization of climate change policies, used by the Foreign, Commonwealth, and Development Office (FCDO) UK, a.o.