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Climate Changes Affect Human Capital

Abstract

Climate change severely impacts critical facets of human capital across the life cycle. This is particularly alarming as both the frequency and intensity of extreme weather shocks continue to increase, and extremes appear to be the main channel of causality. At the same time, human capital has a vital role in driving effective climate change mitigation and adaptation. Here, we provide a framework for analyzing the multiple interlinkages between climate change and human capital and document the existing evidence on the impacts of climate change damages, and the effects of climate change mitigation and adaptation, on human capital across the life cycle. The framework presents two channels through which human capital is affected: direct effects on health, nutrition, and wellbeing, and indirect effects through changes in economic systems, markets, and through damage to infrastructure. These two channels call for different policy interventions, focusing on the different stages of the life cycle. For mitigation and adaptation, we find that while these are overall clearly beneficial, they are also associated with significant human capital costs for specific sectors and groups in society. Ignoring these costs can only lead to worse outcomes, as it can lead to diminishing public support for the required mitigation and adaptation (as has arguably been the case with globalization). Since there is also evidence that high human capital improves adaptation and mitigation, this suggests that adaptation and mitigation that accounts and compensates for these 'sectoral' losses can create a virtuous cycle that leads to positive outcomes for both climatic action and human capital.

JEL-Codes: I140, I150, I240, I250, Q540.

Keywords: climate change, human capital, mitigation, adaptation, health, education, labor.

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1. Introduction

Greenhouse gas emissions have caused significant warming and other climatic changes in every region around the world. Thousands of studies have documented increases in temperature and other climatic changes on the Earth's land cover, as well as in the atmosphere and oceans. The most recent IPCC (2021) report concludes that global surface temperatures will continue to increase until at least the mid-century under all emissions scenarios. They find that global warming of 1.5°C and 2°C will be exceeded during this century unless deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades. Many other changes in the climate system will become more pronounced as well, in direct relation to the increase in global average temperatures (IPCC, 2021).

Most importantly, climate change is increasing the likelihood of many types of extreme weather events. With every increment of global warming, increases in the frequency of episodes of extreme temperatures or precipitation become more pronounced. There is a lot of evidence documenting more heatwaves, wildfires, droughts, heavy rainfall, and floods on the global scale (IPCC, 2021). In addition to these, many other aspects of the global climate are changing. Documented evidence shows melting glaciers; diminishing winter snowpack; shrinking sea ice; rising sea levels; ocean acidification; and increasing atmospheric water vapor.

Over the last century, much progress has been made in improving human capital. Nowadays, many people lead healthier, longer, wealthier, and happier lives (Goldin, 2016). Education levels have risen enormously since the nineteenth century, following a transformation from informal education and training to mass schooling. In terms of health, human prospects have also improved enormously. Around 1600, people were short and frequently suffered from infectious diseases (Goldin, 2016). Increased resources have since then allowed people to invest more in their health by consuming more calories, proteins, and micro-nutrients, which led to large improvements in human health. It is noteworthy that the relationship between incomes and health is twofold: on the one hand, income allows people to invest in their health; and on the other hand, health also allows people to be more productive, have higher earnings, and accumulate more resources (Bleakley, 2007; Almond, 2006). People became healthier, taller, stronger, live longer, contract fewer diseases, and suffer less. Mortality has declined dramatically over time. For example, life expectancy at birth in the United States increased by about 39 years from 1800 to 2020.[4] In addition, most infectious diseases became less frequent, and their consequences are now much less severe.

Climate change poses a threat to this progress in life expectancy and educational attainment, and for human capital more broadly, by affecting health, nutrition, learning, skills and employment outcomes. For instance, impacts of climate change on education may arise from extreme weather events, such as heavy rains, which damage educational facilities. Extreme weather events may also reduce the availability of safe drinking water, compromise sanitation and increase the incidence of water-related diseases such as malaria and diarrheal

[4] Source: *National Center for Health Statistics*. National Vital Statistics System, Mortality. Retrieved from https://www.cdc.gov/nchs/

diseases, leading to absenteeism and possible withdrawal of children from school and older individuals from work. Similarly, droughts and increasing temperatures lead to poor harvests and food scarcity, negatively impacting incomes of agricultural households. In coping with the effects of shocks, households may engage in strategies that also undermine human capital accumulation, such as cutting back on medical expenses or withdrawing children from school.

Impacts of climate change on human capital may differ according to the stage of an individual's life cycle. Impacts for children in utero to early childhood can be particularly severe and long-lasting. For example, a study in Northern Pakistan shows that children under age 3 exposed to a large earthquake accumulated large and persistent height deficits (Andrabi et al., 2021). Older school-aged children may also suffer more from the long-term consequences of not being able to attend a school or from dropping out of the formal education system altogether (Garg, Jagnani, and Taraz 2017;Shah and Steinberg, 2017). Adults in the job market may lose their job, and these losses can also persist (Almond et al., 2005). Due to climatic changes, even retirement decisions could be altered. In this context, it is essential to understand the effects climate change may have on the formation, utilization, and conservation of human capital throughout the life cycle.

This paper collates the evidence of the multiple interlinkages of climate change with human capital. Using a framework for understanding the various ways climate change affects human capital, we document and organize the evidence on the impacts of climate change damages and the effects of climate mitigation and adaptation on human capital across the various stages of the life cycle. We show that climate mitigation and adaptation policies are beneficial in the aggregate, but they also impose significant costs for specific sectors and groups in society which, we suggest, need to be addressed. Finally, we conclude by arguing that human capital also has a vital role in driving climate change mitigation and adaptation policies. Thus, suitable policies can also create a virtuous cycle that delivers positive outcomes for both climate change and human capital, and have one reinforce the other.

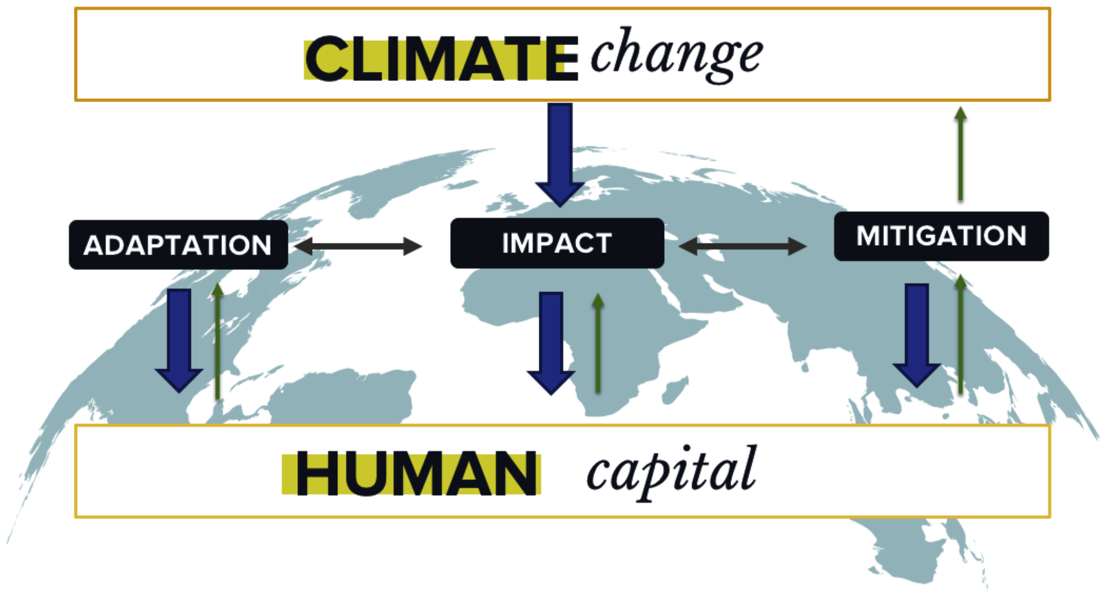
One additional caveat is worth mentioning already. The focus of this paper is mostly on the low- and middle-income countries as these are more exposed and more vulnerable to many climate changes relative to high-income countries. However, where the evidence exists for high-income countries only – as is largely the case for mitigation, for example – we also review it.

The conceptual framework detailed in the next section provides an opportunity to organize the discussion. Section 3 analyzes the implication of the *impacts* of climate change on human capital. Section 4 focuses on the implication of climate change *mitigation* actions – i.e., the transition to a lower greenhouse gas emissions world – and how these actions affect human capital through these domains and life cycle stages. Section 5 synthesizes some of the evidence on the effects of *adaptation* to climate change on human capital by focusing on three main topics chosen by their relevance and the strength of the available evidence. The three are migration, family planning and agriculture. The last section discussed the policy implications of the effects described in sections 3-5, and some of the most relevant policies for protecting human capital from the adverse effects we previously described. Finally, we also highlight several knowledge gaps for future research.

2. Human Capital and Climate Change: An Analytical Framework

The focus here is on ways in which climate change affects human capital, but at the outset we note that there are two-way links between climate change and human capital, with human capital determining vulnerability, and consequently damages from climate change, and also shaping adaptation and mitigation trajectories (Figure 2.1).

Figure 2.1 The links between Climate Change and Human Capital

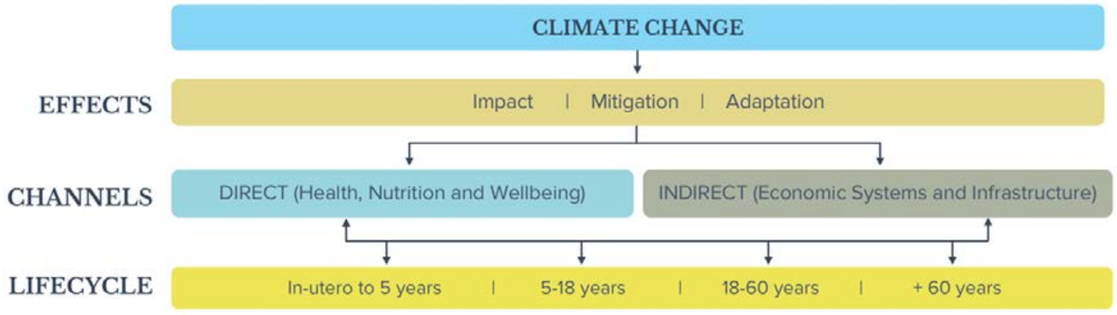


Note: Blue arrows show the direction of the causal links from Climate Change to Human Capital. Green arrows show the direction in which Human Capital may also affect Climate Change.

Over the past years, the link between damages and losses associated with climate change, and human capital, has been receiving more attention, in part because of the increasing number of adverse extreme weather events adversely affecting communities across the world. The other two links – from mitigation and adaptation to human capital - are very much under-researched. Still, although the literature on the mitigation and adaptation effects on human capital is limited, these do pose a potential and specific threat for human capital.

Figure 2.2 depicts the conceptual framework utilized to comprehend the effects and pathways by which climate change impacts human capital throughout the life cycle.

Figure 2.2 Analytical Framework: Climate change affects Human Capital



2.1. Impacts, Mitigation, and Adaptation

The conceptual framework is comprised of the three main effects associated with: (1) *Impacts*; (2) *Mitigation*; and (3) *Adaptation*, as defined in the climate change literature, and by the Intergovernmental Panel on Climate Change (IPCC, 2021).

Impacts refer to the consequences and outcomes of the interactions of climate-related hazards, including extreme weather and climate events, on human and natural systems. These impacts can be quite broad, and generally refer to effects on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social, and cultural assets, services (including ecosystem services), and infrastructure. Naturally, impacts can be either adverse or beneficial.

Climate *mitigation* is defined as human interventions aimed at reducing the net amount of greenhouse gases (GHGs) emitted into the atmosphere. As is the case for impacts, such mitigation measures – e.g., shifting energy generation to sustainable sources – may have mixed effects on human capital accumulation, protection, and use. For example, the transition to sustainable energy sources could lead to job losses in industries that rely on carbon-based production, such as coal mining. *Adaptation* refers to the adjustment process that societies undertake in the face of current or future (expected) climatic change. Adaptation actions seek to moderate or prevent harm or take advantage of beneficial opportunities. Adaptation, like mitigation, can also have both positive and negative effects on human capital.

2.2. Direct and Indirect Effects

The framework above presents two channels. The first channel describes the direct effects that climatic changes have on the health, nutrition, and wellbeing of individuals and households. The second includes indirect effects that are transmitted through changes in economic systems and markets, and in some cases, through damage to infrastructure. Those indirect effects can therefore occur even in places where the impacts, mitigation, and adaptation are not happening and be transmitted through, for example, international trade channels.

Direct effects: Health, Nutrition, and Wellbeing.

Health is often the most critical and persistent channel through which climate change affects human capital. Climate change harms human health by increasing the frequency and intensity of extreme weather events, directly injuring individuals, and exacerbating existing disease burdens. Climatic changes also provide additional favorable environments for increased vector-borne diseases (e.g., malaria, dengue), it increases heat stress, and the stresses associated with these. It may also adversely impact mental and psychological health. Those with the weakest pre-existing health, the weakest health protection systems, and the least capacity to adapt suffer the most adverse direct effects.

Nutrition is also an essential aspect of human capital development. Climate change might have direct effects on the availability of water and food supplies. Higher temperatures, variable rainfall, and extreme weather events such as heatwaves, floods, and droughts directly impact food crops, livestock, and consequently food security. This channel is especially important for households who engage in subsistence agriculture.

Climate change can also affect people's mental health and wellbeing. Severe weather increases the risk of injuries and death, and therefore the psychological responses to this risk. Weather-related disasters can lead to adverse mental health consequences, especially if they damage homes and livelihoods or cause the loss of loved ones. The mental health impacts of these events can range from temporary distress symptoms to clinical disorders, such as anxiety, depression, and post-traumatic stress disorder.

Indirect effects: Economic Systems and Infrastructure.

Climatic change affects economic systems, markets, and income-generating activities. In turn, these have consequences for investment in and development of human capital. For example, higher temperatures and changes in precipitation affect agriculture, which may reduce the quantity and quality of food harvested. The loss of cash crops can result in loss of income for agricultural households, and higher prices, and therefore lower real incomes, for urban ones. These income losses tighten budgets and can lead to reduced investment in health, and education, thus affecting human capital development. In another example, climatic changes may also trigger adaptation in farming households, requiring them to adopt new crops and agronomic methods for which they have little experience, consequently rendering their existing accumulated knowledge obsolete.

Infrastructure systems such as roads, bridges, water, sanitation, and power could also be destroyed or disrupted, reducing the amount of services they provide, and thus indirectly affecting economic activity and human capital accumulation and use processes as well.

2.3. The Life Cycle Stages

The effects of climate change on human capital are not uniformly distributed along the life cycle. There are age-specific vulnerabilities and risks, highlighting the importance of denoting them separately, and thus enabling the development of the appropriate interventions. Although the level of impacts is typically higher in earlier stages of life, with significant long-term and sometimes irreversible consequences that can persist for very long, climate change mitigation and adaptation can also have more adverse effects at later stages of life.

Prenatal and early childhood (In utero to 5 years old)

In utero and early childhood investment strongly influences adult outcomes, and climate change can compromise such investments. It is well established that during early childhood, investments in human capital yield particularly long-lasting high returns (Heckman, 2011; Heckman et al., 2021). These early childhood investment raises future productivity and lowers the costs of future investments (Carneiro & Heckman, 2003; Cunha et al., 2010). Conversely, climate change may prevent these early-life investments in human capital, with a potential for long-lasting adverse effects. In-utero is a particularly critical stage of development; through epigenetic channels, damages wrought in-utero can even be transmitted to future generations and thus entail costs that persist for many decades.

School-aged children (5 to 18 years old)

Education is obviously a key component of human capital, so not surprisingly the schooling years are also particularly important. Conventionally, education outputs and outcomes are easily measured in terms of school attendance, test scores, acquisition of testable skills, and the number of years of education completed. There is extensive evidence of the importance of schooling for wellbeing and the economic returns from such schooling (e.g., Psacharopoulos and Patrinos, 2018). Climate change has the potential to derail educational achievement with increasing temperatures and more intense extreme weather events posing particular risks. The literature on human capital accumulation notes that educational achievement is highly path-dependent. Thus, decreased attendance or diminished learning have potentially long-lasting effects associated with adverse individual and social consequences.

Youth to Adulthood (18 to 60 years old)

For youth and adults, the most relevant consequences of climate change are on jobs, earnings, and health. Adverse shocks due to climate change may cause individuals in their youth and adulthood to make labor decisions that affect their human capital. As suggested by Salvanes et al. (2021), decisions on human capital investment, location, family structure, and career may all vary depending on the types and timing of shocks experienced. Here, we note that mitigation poses particular risks, as it involves significant differential impacts on different sectors and employments, with potentially more adverse impacts on carbon-intensive sectors, and on the less-trained and specialized (unskilled) labor force.

The Elderly (more than 60 years old)

Older adults can also be vulnerable to climate change. Several physical, psychological, and socioeconomic factors contribute to this vulnerability, including fragile health, impaired mobility, social isolation, and financial dependence on fixed incomes or the extended family.

An additional vulnerability is the diminished ability of the elderly to switch employment, retrain, or be hired, even when they prefer remaining in the labor force. For instance, it is well documented that the probability of permanently leaving the labor force for a displaced worker increases with age.

3. Climate Change *Impacts* and Human Capital

Climate change impacts include both those impacts associated with sudden-onset events and those that are caused by more gradual impacts of climate change. The consequences of these climate change impacts are presented in each stage of the life cycle and across the two channels described earlier (direct and indirect effects). Table 1 pre-emptively summarizes what we find. It describes the intensity of the impact of these climate events on human capital across the life cycle and along the different channels. It also provides our assessment of the strength of the evidence about these effects in the different life-cycle/channel combinations.

There is abundant literature that links weather shocks to human capital outcomes. Clearly, not all-weather shocks are related to climate change, and the literature that identifies the role of climate change in these events (extreme event attribution - EEA) is recent and incomplete. There are few papers that make the distinction between the climate change component of extreme weather disasters and the 'normal' impact of these events (e.g., Smiley at al., 2022; Newman and Noy, 2022). Consequently, here we discuss the evidence about extreme weather events, without distinguishing the specific role of climate change in shaping the frequency, location, and intensity of these events.

The extreme events documented here include increased temperatures, extreme precipitation and flooding, and droughts. Although hazards such as earthquakes and tsunamis are clearly not strongly connected to anthropogenic climate change, they are included in the evidence we discuss as they provide evidence about similarly unanticipated shocks, helping shed some light on the plausible channels and magnitudes of impacts associated with extreme weather disasters.

Table 1. Impact of Climate Change and Human Capital: Effects and Evidence

Impacts

LIFECYCLE	DIRECT EFFECTS	INDIRECT EFFECTS
Prenatal and early childhood (-1 to 5)	+++	+++
	+++	+++
School-aged children (5-18)	+++	+++
	+++	++
Youth and adulthood (18-60)	++	++
	++	++
Elderly (+60)	+++	+
	++	+

Note: The degree of impact (represented in red) denotes the severity of climate change effects on human capital through the identified pathway, categorized as low, medium, or high. The strength of the evidence (represented in blue) reflects this report's evaluation of the quality, consistency, amount, and type of evidence, which is classified as limited, medium, or robust.

3.1. Prenatal and Early Childhood

Direct effects: Health, Nutrition, and Wellbeing

Prenatally and during their early years, children are biologically and psychologically most vulnerable to climate change's direct effects on health, wellbeing, and nutrition. This life stage is also the one stage in the life cycle with the most readily available and robust evidence (see Table 1). The impacts of climate change include increased malnutrition, increased rates of infectious and respiratory diseases, heat stress, morbidity and mortality, and psychological trauma from extreme weather-related disasters. For example, evidence on rural households in central Mexico showed that children ages 0–5 were more susceptible to disease as a result of weather-related shocks (de la Fuente and Fuentes-Nieva 2010).The fact that in-utero and infant health is the most sensitive to climate change's multiple and cumulative impacts is especially relevant considering the evidence pointing to the persistent impacts of early life environmental conditions on long-run outcomes (Almond and Currie, 2011).

Extreme weather events represent an unpredictable and unusual source of stress during pregnancy, affecting the health and wellbeing of infants. Pregnancy is a period of increased vulnerability to many environmental hazards, including extreme heat (Strand et al., 2012) and infectious diseases such as malaria and foodborne infections. For example, weather anomalies experienced in utero and during infancy are associated with an increased risk of child undernutrition (Dimitrova and Bora, 2020), and fetal exposure to droughts could lead to poorer health outcomes in early childhood (Nguyen et al., 2022). Similarly, exposure to a hurricane during pregnancy increases the probability of abnormal conditions in the newborn (Currie, 2013).

Previous research also shows that in-utero exposure to disasters has significant long-term effects on health, education, and many income-generating processes. A study of the impacts of the catastrophic 2004 Indian Ocean earthquake and tsunami on child growth found that in-utero exposure to this event caused children to be shorter at ages two and three in Aceh (the most heavily affected region in Indonesia), with results more significant in magnitude for mothers living closer to the most exposed coastal areas (Frankenberg et al., 2013). Caruso and Miller (2015) also found that education acquisition (years of schooling completed) diminished for kids who were in-utero during the 1970 Ancash earthquake in Peru. The longer-term outcomes they follow also suggest that welfare of the affected individuals is negatively impacted in adulthood.

Maternal heat exposure is also a risk factor for several adverse maternal, in-utero, and neonatal outcomes. These include changes in gestation length, birth weight, stillbirth, and neonatal stress due to exposure to unusually hot temperatures (Kuehn and McCormick, 2017; Strand et al., 2012; Sun et al., 2020).

Extreme rainfall can also significantly threaten children's growth and development. Specifically, increases in rainfall are documented to make diseases such as diarrhea, cholera, and malaria more prevalent (Umbers et al., 2011), and contracting such diseases during pregnancy is likely to generate unfavorable birth outcomes (Ngai et al., 2020). For instance, Dimitrova and Bora (2020) and Skoufias and Vinha (2012) find that children experiencing excessive rainfall in-utero or during infancy face an increased risk of contracting diarrhea and being stunted. Another study found that excessive rainfall makes Nigerian children shorter for their age and thinner for their height (Rabassa et al., 2014). Le and Nguyen (2021) examine the impacts of in-utero exposure to rainfall shocks on child health in 55 low and middle-income countries and find that this rainfall variability is negatively associated with child health and that children from disadvantaged backgrounds are more likely to be affected.

It is worth noting, though, that increases in the average rainfall (rather than extremes) are potentially beneficial. In Indonesia, Maccini and Yang (2008) found that higher aggregate amounts of seasonal rainfall in regions relying on agriculture correlate positively with a person's subjective health status, their lung capacity, and their height. Higher early-life rainfall also has significant positive effects on the adult outcomes of women; those with 20 percent higher seasonal rainfall (relative to the local norm) are 0.57 centimeters taller and complete 0.22 more schooling grades.

Climate change can also have detrimental impact on the availability of clean water; and the absence of clean water helps spread infectious diseases, especially vector-borne ones (McIntyre et al., 2019). Particular attention has been devoted to floods since these events often result in the release of untreated sewage and wastewater into the water supplies or onto land and thus contaminate watersheds and crops. In addition, flooding can also mix animal waste with drinking water sources. Children's immature immune systems make them more susceptible to infectious disease pathogens from crop and water contamination or the spread of vector-borne pathogens (cholera and other diarrheal diseases and malaria and dengue fever, respectively).

An additional channel through which excessive rainfall can affect a child's health is reduced access to healthcare services through, for example, less frequent consultations with doctors. The existing evidence suggests that this is a relevant channel. Jensen (2000), in his study of rain shocks between 1986 and 1987 in Cote d'Ivoire, found that the percentage of sick children taken for consultation after a rainfall shock in 1986-87 declined by around 1/3 for those who received the negative shock, and increased slightly for boys in regions with average rainfall. In Nicaragua, children in areas affected by Hurricane Mitch were 30% less likely to be taken for medical consultation - conditional on being sick - and their probability of being undernourished increased by 8.7 percentage points (Baez and Santos, 2007).

Extreme temperatures have been similarly studied. A recent project in West Africa found that extreme heat exposure increases the prevalence of both chronic and acute malnutrition for children aged 3-36 months (Blom et al., 2022). The evidence suggests adverse temperature shocks have a negative impact on height (as a measure of physical development), with the very young being especially sensitive to temperature exposure (Deschenes and Greenstone, 2011; Deschenes and Moretti, 2009). The direct effects of heatwaves on children include hyperthermia, heat stress, renal disease, and respiratory illnesses (Surdu, 2008), to which infants and children are especially vulnerable due to their immature temperature regulatory systems (Knobel and Holditch-Davis, 2007).

There is also extensive evidence of climate change's adverse effects on children's nutrition. Years with lower rainfall, temperature shocks, and drought spells damage child health through nutritional deprivation. Early nutrition and health investments show that better-nourished children perform significantly better in school, which results in higher educational attainment, wages, and productivity (Glewwe et al., 2001; Alderman et al., 2001). Children are more vulnerable than adults to deficient nutrition and require three to four times the amount of food on a body weight basis. With insufficient energy intake, children fail to fully reach their physical growth potential. This lost growth is never fully regained, so these individuals end up shorter in height and with reduced body mass (Martins et al., 2004). This growth failure in early life has been shown to have profound adverse consequences over the affected lifespan (Hoddinott, 2013). It could lead to worse performance at school (less learning or fewer grades attained) and ultimately lower productivity and thus income in labor markets (Tiwari et al., 2017). Even the premature onset of chronic diseases in later life was shown to be associated with adverse nutritional outcomes in childhood, so life expectancy is decreased (Alderman et al., 2006).

Malnutrition effects are particularly acute for children in developing countries and regions with high dependence on agriculture-sourced income. For example, Chen and Zhou (2007) exploit variations across regions and cohorts to estimate the health and economic effects of the

1959-61 famine in rural China.[5] They find that exposure to famine in early life was associated with lower height and income during adulthood. Similarly, the incidence of infant malnutrition increased by more than three times among the households most exposed to intense rainfall during Hurricane Mitch in Nicaragua in late 1998 (Baez and Santos, 2007). In addition, Rice et al. (2000) show that undernourished children are more susceptible to infections and chronic diseases and face a higher risk of premature mortality related to these diseases.

Even more temperate fluctuations in drought conditions in poor countries, and consequently temporary undernutrition, have direct effects on children's stunting and human capital accumulation. They depress crop production, thus reduce household incomes, and worsen food security. In this context, Miller (2017) documents that Ethiopian children exposed to seasonal food scarcity during the intra-uterine period tend to have shorter stature in their childhood years. Alderman et al. (2006a) traced the 1982-84 droughts in Zimbabwe and found that short-term nutritional shortfalls persisted and manifested in reduced height. Specifically, they link exposure to transitory shocks experienced by Zimbabwean children to their preschool nutritional status before age three. The temporary hunger followed by stunting of those children aged between 12 and 24 months at the time of the drought –recognized as a critical time in a child's growth– led them to lower average height (2.3 cm in their results) in late adolescence. The same study on Zimbabwe also found that this stunting led to delays in school enrolment (3.7 months) and reduction in grade completion (0.4 grades) 13 to 16 years after the droughts (Alderman et al., 2006a). In a similar study, Alderman, et al. (2006b) report evidence of long-lasting drought impacts on the human capital of Tanzanian children through the same causal links.

Air pollution levels are also related to climate change, with a high impact on children's health. Higher temperatures due to climate change accelerate ozone formation from its precursors (volatile organic chemicals, carbon monoxide, and nitrogen dioxide). In addition to increased mortality, ozone is associated with decreased lung growth and function and exacerbates children's asthma and respiratory tract infection. Higher temperatures, higher humidity, and greater CO2 concentrations in the atmosphere also promote the growth of aeroallergens (such as pollen and mold), leading to more allergies and asthma in children (Bambrick, 2005, Syed et al., 2103).

Children are particularly sensitive to these exposures given their developing immune and respiratory systems. They have a higher respiratory rate and take in more air on a bodyweight basis than adults. In addition, their immature immune systems place them at greater risk from inhaled toxins, and higher sensitivities to allergies. Direct toxic effects of fossil fuel combustion pollutants are also reported, including increased infant mortality, lower birth weight, deficits in lung function, respiratory symptoms, childhood asthma, bronchitis, developmental disorders, and increased risk of cancer. In this sense, air pollution, which is a side effect of GHG emissions, is strongly associated with increased risks of infant death and adverse birth outcomes (Perera, 2017).

[5] This famine, during the Great Leap Forward, was of course largely related to human causes, but there is no reason to expect that food shortages triggered by other causes will have any different impact on human development.

Epigenetic Channels

Recent studies show that early-life adversity not only impacts future health but may also be passed onto future generations. The emerging evidence of epigenetic inheritance mechanisms and how trauma is transferred across generations may have important implications for human capital accumulation and its vulnerability to climate change. Epigenetics refers to potentially heritable changes in the genome that can be induced by environmental events. This epigenetic evidence points to the importance of parental stress's impact on children, which may have occurred through epigenetic channels involving altered DNA methylation and gene expression.[6]

Trauma can transmit from parent to child through epigenetic mechanisms either through the offspring's early environmental exposures, such as postnatal maternal care, or in utero exposure through maternal stress. Some of the most compelling evidence of prenatal stress's effects on intergenerational health comes from the Dutch famine of the mid-1940s, at the tail-end of the Second World War (Roseboom et al., 2011). For example, research has documented reduced birth size and poorer health in later life in the grandchildren of women pregnant during the famine, suggesting that the stress of starvation has intergenerational effects (Painter et al. 2008). Similarly, Costa et al. (2018) studied whether paternal trauma was transmitted to the children of survivors of Confederate prisoner of war (POW) camps during the US Civil War. They find severe paternal hardship as a POW - extreme overcrowding, poor sanitation, and malnutrition - led to high mortality among sons born after the war and survived to the age of 45. They do not find the same effect for the POWs' daughters; and find that adequate maternal nutrition countered the effect of paternal POW trauma in a manner most consistent with an epigenetic explanation. Another study found that the children of the survivors of the Holocaust had epigenetic changes to a gene linked to their cortisol levels, a hormone involved in stress responses (Yehuda et al., 2016). Although the study was small, it points to epigenetics as a possible explanation for the documented higher rates of PTSD symptoms in children to parents who have experienced trauma in early life (or even in utero).

Evidence of the intergenerational effects through epigenetic channels provide a potential insight into how shocks can impact human capital accumulation and protection for a very long time. Though the epigenetic literature is still nascent, with little investigation of the economic implications of these links, the studies mentioned above show how epigenetic markers could change in response to many of the processes that result from climatic events—for example, migration, or nutritional and psychosocial stress. The identification of these epigenetic channels also may imply that the net present value of the adverse impacts we now identify are under-estimated, as they last much longer than we previously considered plausible.

[6] Though the readability or expression of genes is modified without changing the DNA code itself, chemical tags are added to or removed from the DNA in response to changes in the environment. These tags turn genes on or off, offering a way of adapting to changing conditions without inflicting a more permanent shift in our genomes (Mulligan, 2016)

Indirect effects: Economic Systems and Infrastructure

Household income loss directly affects investment decisions and the human capital of early childhood. A negative shock, and thus the lack of sufficient investment occurring at an influential stage of human capital formation, will not only affect the child's current skills but also reduce their future skill accumulation. The fact that early-childhood environment shape life-long human capital accumulation is well established (Cunah & Heckman, 2007; Almond et al., 2017). Furthermore, as health in early life is a more significant determinant of adult outcomes in children from lower socioeconomic status households, the negative effects of shocks persist and accumulate over time even more (Currie and Vogl, 2013).

Parenting decisions shape the foundation for the lifetime development of skills before children enter formal schooling (Francesconi and Heckman, 2016). This is particularly important under contexts of adversity, such as a climatic shock, where parents are more likely to underinvest when children need additional support the most. Mothers play a key role through nurturing care and investments, as they are often the primary caregiver during the child's earliest years. If a negative shock disrupts a mother's capacity and ability to invest in her children during these early years, this might have immediate consequences on the human capital accumulation of her children during their early years, with long-lasting consequences for child development (Almond, 2006).

There is a consistent acknowledgment of the importance of caretakers in buffering young children against the potentially harmful effects of early adversity (Currie and Almond, 2011; Brito and Noble, 2014). The timing of these remediations matters especially during the critical periods of development (Cunha and Heckman, 2007). The literature on whether parents compensate for or reinforce their children's wellbeing in response to shocks the parents experience remains mixed (Attanasio et al., 2017; Yi et al., 2015). In some cases, parents make compensatory changes, thereby reducing the effects of shocks on their children's human capital (Yi et al., 2015). However, there is also some empirical evidence that parents are more likely to reinforce adverse shocks when they are experiencing situations of adversity themselves (Currie and Almond, 2011).

3.2. School-aged children

Direct effects: Health, Nutrition, and Wellbeing

The documented evidence shows that the effects of climate change on health, well-being, and nutrition on school-aged children can be substantial (Table 1). These various effects can, again, lead to severe and long-lasting poor education outcomes, a crucial factor for human capital accumulation. Currie (2009) shows that health problems significantly affect children's educational and labor market outcomes. Temporary poor health and child malnutrition reverberate into the different processes of human capital accumulation, such as school performance, cognitive development, and earnings and productivity (Baez, 2010). These effects suggest that health could play an essential role in the intergenerational transmission of economic status.

Heat exposure affects the rate of skill formation and school enrollment. A study by Park et al. (2021) combines standardized achievement data from PISA for 58 countries to show that learning decreases with an increase in the number of hot school days. These results provide evidence that climatic differences may contribute to differences in educational achievement across and within countries by socioeconomic status. Similarly, evidence from Southeast Asia demonstrates that experiencing higher-than-average temperatures is associated with fewer years of schooling (Randell et al., 2019). In this sense, thermal conditions in the physical learning environment appear to causally influence cumulative learning with important implications for human capital accumulation.

Climate change directly affects human capital and the well-being of children who lose parents in extreme weather disaster events. Various studies analyze the long-term impacts of parental death as a result of an unanticipated shock. For example, a study by Frankenberg et al. (2014) measures the impact of both parents' death on the well-being of children in the aftermath of the 2004 Indian Ocean Tsunami. They find that the death of both parents has a large, negative impact on the human capital accumulation of 15- to 17-year-olds of both genders. In addition, the loss of only a father has negative implications for older males, who acquired less education after the tsunami than similar males whose parents survived the tsunami. They find little evidence that parental death affects the human capital accumulation of younger school-age males.

Nutritional intake is essential to human capital development, and malnutrition can obviously also affect school-aged children. Glewwe et al. (2001) tracked children from a large panel sample collected in the Philippines. After controlling for several confounding factors, they found that those better nourished were more likely to start school earlier and repeated fewer grades. Similarly, evidence shows that improved nutrition during the schooling years may increase educational attainment, the likelihood of completing primary and secondary school, and increase test scores (Maluccio et al., 2009). Poor temporary health setbacks and malnutrition can have persistent effects because they reverberate in the process of human capital accumulation, such as through school attendance and performance. Children are generally at greater risk when food supplies are restricted, with further risks for lower-income households. Children from low-income households with food insecurity are more likely to be at developmental risk than those from low-income households with food security. These effects include high impact on health and mortality (Black et al., 2008). Air pollution has been shown to increase school absences. A study by Currie et al. (2009) uses panel data methods in a large sample to estimate the causal effect of air pollution on absenteeism. In turn, absenteeism negatively affects learning and test scores. These effects are relevant both in the short and long term for human capital accumulation (Ebenstein et al., 2016).

Indirect Effects: Economic Systems and Infrastructure

Resource-constrained households sometimes resort to the labor of children to cope with the negative impact of climate hazards. The existence of a positive link between household income and schooling is well established. Children are sometimes used as a risk coping instrument when shocks such as extreme rainfall, droughts, and floods affect the incomes of (mostly agricultural) households (Santos, 2007; Beegle et al., 2003). When households have difficulties sustaining consumption, children can be taken out of school to save on costs and sent to work to help the household absorb the income shock. Children can work for wages, in home-based enterprises, or as substitutes for parents doing household chores. An analysis of rural households in Central Mexico showed that droughts lead to children being taken out of school and inducing them to increase their labor-force participation when other risk-coping instruments are insufficient (de Janvry et al., 2006). Similarly, heavy rainfalls in Uganda reduced school attendance by almost 10%. In Guatemala, evidence from a tropical storm shows a reduction of 8.4% in the probability of children being enrolled (Bustelo, 2011).

Carneiro et al. (2021) examine the importance of the timing of income shocks for the human capital development of children and find that a child's education is maximized when fathers experience a stable and balanced flow of income across the first 17 years of the life of the child. Replicating the pattern in the previous chapter on early life, the educational effects of negative rainfall shocks are particularly pronounced for younger children attending primary schools (Agamile and Lawson, 2021).

These dynamics are more acute in credit-constrained households. If disasters worsen the economic situation of households and these are limited in their access to credit, insurance, or other financial coping mechanisms, taking children out of school may be the preferred choice of many households. One aspect of that problem is that children who leave school temporarily are less likely to return to school subsequently. With such state dependence, temporary shocks that induce parents to take their children out of school may permanently affect their human capital accumulation and even future earnings (de Janvry et al., 2006). Sadoulet et al. (2004) also found that children who withdraw from school during shocks are about 30 percent less likely to continue studying than those who stay in school. Parental reductions in investments in children that appear to be temporary adjustments to difficult times become permanent shifts in educational trajectories (see also Jensen (2000) and Beegle (2004)).

The destruction wrought by extreme weather events also leaves many parents without employment and less time available for leisure and educational activities with their children. Consequently, reconstruction activities inside and outside the household may leave parents and children with less time to spend on the informal "home production" of human capital (Ferreira and Schady, 2008).

Direct effects due to infrastructure damage from disasters can also disrupt the learning process for prolonged periods of time. Because schools play a central role in creating human capital, the damage or destruction of school facilities and other complementary resources, such as bridges and roads, reduces access to education facilities, hinders learning, and reduces instruction time, lowering school quality. Following a storm, roadways may become impassable, transportation is limited, schools' infrastructure is damaged, and schools may remain closed for extended periods. Canceled instruction days, in turn, disrupt teachers' productivity in the classroom and worsen the learning environment (Baez et al., 2010). In this sense, severe damage to physical infrastructure can also have long-term adverse effects on children's educational attainment.

3.3. Youth and Adulthood

Direct Effects: Health, Nutrition, and Wellbeing

For youth and adults, climate change conditions may affect health and labor productivity, with consequences for human capital accumulation and usage. Both the level of impact and the strength of the evidence is considerable, even though it may be less severe than for infants and children. Youth and adult health is affected by climate change through the spread and transmission of vector-borne and water-borne diseases. Tseng et al. (2009), for instance, find that changes in temperatures and humidity significantly affect the probability of people being infected by dengue fever. Several studies have estimated the potential impact of climate change on the distribution and severity of malaria on global and regional scales. These studies conclude that future climate conditions will be increasingly favorable for malaria transmission, particularly in tropical highland regions (Caminade et al., 2019).

Drought has also been found to have detrimental consequences for young adults, both on their psychological conditions and their body mass index. Hoddinott and Kinsey (2001) observed changes in the physiological condition of women in villages affected by the 1994-1995 drought in Zimbabwe. A reduction of 10 percent from the historical level of rainfall was associated with a 1.15% drop in women's body mass index, with the more detrimental effects found for women residing in the poorest households. Along the same lines, Dercon and Krishnan (2000) find drops of about 0.9 percent in the body mass index of adults in households with small landholdings over a short horizon due to poor rainfall using a panel of rural Ethiopian households. Moreover, clear correlations were found between this effect on malnutrition and the ability of adults to perform standard tasks, such as hoeing a field or carrying water.

Such climate change effects on health and sanitary conditions may impact overall labor productivity. Bleakley (2010) argues that health is both human capital itself and input to producing other forms of human capital. Therefore, its impact on the labor market should be assessed through two main channels: on the one hand, physical wellness determines availability to work, while on the other, it influences incentives to invest in human capital as returns rely on not being idled by disease in adulthood. A study by Patankar (2015) examines poor households in Mumbai and their exposure to recurrent floods. Its results show that a consequence of recurring flooding is the loss of workdays every year, which causes a loss of income and productivity. Floods also cause diarrhea in 40 percent of households yearly, malaria in 64 percent, and viral fever in 86 percent. Health impacts and loss of work days involve a direct monetary burden that includes both the cost of treatment and the income loss.

Indirect Effects: Economic Systems and Infrastructure

Disasters and climate change-induced weather events significantly affect labor markets and livelihoods. In Bangladesh, for example, floods were found to reduce agriculture wages by 9% (Banerjee, 2007). Generally, job losses are found to have long-lasting consequences, so it is plausible that losses are associated with disasters are equally persistent. For the more general case, Jacobson et al. (1993) analyze the long-term earning losses of previously longtenured but now displaced workers. They find that earnings of displaced workers begin to fall up to three years before the displacement, then fall sharply at the time, and afterward start to recover. These workers' earnings recover slowly and never reach their previous earnings path again. The authors estimate that these displaced workers suffer long-term losses averaging 25 percent per year. Similar results were found more recently by Couch et al. (2010), where displaced workers face initial reductions of more than 30 percent, and as much as 15 percent six years later.

The empirical literature finds that individuals cope with job losses differently depending on the stage of their career in which they experienced the labor shock. For instance, Salvanes et al. (2022) find that individuals at the beginning of their work career often respond by relocating to other local labor markets or investing more in their human capital. Individuals in the middle of their careers, in contrast, may respond by reducing their fertility and ending their marriages. Lastly, older individuals approaching the end of their working life often respond by permanently exiting the workforce. In this sense, the long-term effects on earnings and employment may be heterogeneous depending on workers' age at the time of the displacement.

Higher temperatures and lack of access to cooling can also impact labor productivity and the well-being of populations. A study in India shows that the effect of temperature on labor explain some fluctuations in daily productivity (Somanathan et al., 2021). The authors estimate reduced worker productivity and increased absenteeism on hot days using data from selected firms. Heat stress is an issue not only for those working outside (e.g. in construction or agriculture) also for those working indoors in environments that are not temperature-controlled. Moreover, at higher temperatures, there is a potential conflict between health protection and economic productivity (Kjellstrom et al., 2011; Subhashis et al., 2013). High heat exposure caused heat strain and reduced work productivity. As workers take longer rests to prevent heat stress, hourly productivity decreases (Sahu et al., 2013).

Orlov et al. (2021) model the future impacts of heat on labor productivity in agriculture, and thus on crop production. They find that the adverse impact of heat on future labor productivity will be larger than any beneficial impact of more air-borne carbon on plant growth. They find that this challenge will be especially severe in tropical countries where heat stress is already a risk for those working outside.

3.4. The Elderly

Direct effects: Health, Nutrition, and Wellbeing

Though the amount of evidence on the impact of climate change on the elderly is limited (Table 1), older people's physical and environmental conditions suggest they are especially vulnerable to the health and wellbeing declines associated with climate change and weather extremes. By increasing morbidity and mortality, the results of these effects have a direct impact on the use of human capital.

Older people are more vulnerable and at greater risk from extreme events such as storms and floods. If an extreme event requires evacuation, older adults find it more challenging to evacuate, have an elevated risk to both physical and mental health, and are more likely to be at risk of mortality. Normal changes in the body associated with aging, such as muscle and bone loss, can limit mobility and make it more difficult to avoid hazardous situations. Some older adults, especially those with disabilities, may also need assistance with daily activities post-disaster thereby making their recovery more difficult and less successful.

Extreme heat exposure can increase the risk of illness and death among older adults. Heat-related death most often occurs in vulnerable elderly people (Basu and Ostro, 2008; Peng et al.,2011). A study by Gamble et al., (2013) shows they are also more likely to suffer from health conditions that limit the body's ability to respond to stressors such as heat and air pollution. Similarly, high prevalence of pre-existing health conditions, use of medications, and autonomic nervous system impairments affect thermo-regulation and perception of extreme heat, making them more susceptible to risk during heatwaves. Heatwaves also affect cognitive function (Laurent et al., 2018). A study of the combined effects of warming temperatures and an aging population in Korea projected a four- to six-fold increase in heat-related mortality by the 2090s when accounting for temperature and demographic change (Lee and Kim, 2016).

Increased temperatures may lead to mosquitoes expanding their ranges and being present for longer seasons. Again, the elderly are more vulnerable to these vector-borne infectious diseases. Poor air quality worsens respiratory conditions common in older adults. Air pollution, often tied to increased GHG emissions, can also increase the risk of a heart attack in older adults. Polluted air was responsible in 2015 for 6.4 million deaths worldwide. It is responsible for 19% of all cardiovascular deaths worldwide, 24% of ischemic heart disease deaths, 21% of stroke deaths, and 23% of lung cancer deaths (Landrigan, 2017). All of these are much more likely risks for the elderly.

Indirect Effects: Economic Systems and Infrastructure

Climate change may induce older workers to retire, though there is little evidence documenting the effect. However, it seems plausible that in a setting where old adults choose when to exit the labor force, external shocks may push them to retire at an earlier age, thus losing years where their accumulated knowledge is not being used. Even when the job loss is only temporary, participation in the labor market might affect contribution levels to retirement payments (in retirement saving schemes), thus affecting the elderly’s disposable income post-retirement.

3.5. The Gendered Impacts of Climate Change

There is a lot of evidence that men and women are differentially affected by the impacts of climate variability and change, so it is worthwhile to focus on this distinction here when evaluating the human capital implications of these gender differences (there is little research on gendered differences in the effects of mitigatin and adaptation). Generally, the effects of shocks on individuals, and their ability to adapt to them, depend on sociodemographic factors, including such as gender, health status and disability, ethnicity or race, caste or religion, and socio-economic status. There is significantly more evidence on gender differences.

Furthermore, gender dimensions of vulnerability to the impacts of climate change may also derive from differential access to the resources determining vulnerability and the capacity to adapt. For example, in many rural economies and resource-based livelihood systems, it is well established that women have poorer access than men to financial resources, land, education, and health, and all of these may reduce vulnerability and increase coping capacity.

Globally, disasters such as droughts, floods and storms kill more women than men, and tend to kill women at a younger age. In a sample of up to 141 countries over the period 1981-2002, a pioneering study by Neumayer et al. (2007) analyzed the effect of disaster intensity and its interaction with the socioeconomic status of women on the gender gap in life expectancy. Their results show the gender-gap effects on life expectancy tend to be greater in more severe disasters, and in places where the socioeconomic status of women is particularly low. However, in some instances, men may be more vulnerable as in many cultures they are often expected to protect assets and engage in life-saving behaviors that increase their likelihood of mortality. In Hai Lang district, Vietnam, for example, the number of men who lost their lives while participating in search, rescue, and field protection during flooding was higher than that of women (Campbell et al., 2009). A similar gender imbalance was identified in the very costly Bangkok floods of 2011 by Noy (2015).

Men tend to get more opportunities to equip themselves with new skills and preparation to cope with disaster than women. Moreover, women are often discouraged from learning lifesaving skills, such as how to climb trees or swim. Both factors put them at a disadvantage when floods or storms hit. Studies in Bangladesh, for example, show that women do not learn to swim and so are more vulnerable when exposed to riverine flooding or storm surges (Röhr, 2008). In Nicaragua, the construction of gender roles means that middle-class women are expected to stay in the house, even during floods and in risk-prone areas (Bradshaw, 2010). In more traditional environments, women are often not permitted to evacuate their homes without consent from their husbands or elder men in their families or communities.

Gender differences are also visible in household food allocation and their health impacts. In some places, women eat less in times of food shortage and become weaker in periods of prolonged stress. Nelson and Stathers (2009) explore the gender differences in decision-making, the divisions of labor, access to resources, and knowledge – all with respect to environmental stress - in Tanzania. They demonstrate how women experience food and nutrition insecurity because food is preferentially distributed among other family members. Another reason for increased vulnerability of women is pregnancy. Pregnant women are especially susceptible to water-borne diseases (e.g. diarrhoea, cholera), and droughts bring these health hazards through reduced availability of clean water for drinking, cooking and hygiene, and through food insecurity.

Heat stress is also more dangerous to women during pregnancies. But pregnancy is not the only reason for increased vulnerability of women. Vulnerability to heatwaves, for example, also varies by sex, and beyond the impact on pregnancies. More women than men died during the 2003 European heatwave, and the majority of European studies have shown that women are more at risk, in both relative and absolute terms, of dying in such events (Kovats et al., 2008).[7] A multi-city study showed geographical variations in the relationship between sex and mortality due to heat stress: in Mexico City, women had a higher risk of mortality than men, although the reverse was true in Santiago and São Paulo (Bell et al., 2008).

Household responses to income shocks due to weather anomalies impact the quantity of schooling children receive, with more significant effects for girls. These responses to short-run shocks have long-term consequences on women's human capital development. For example, Björkman-Nyqvist (2013) shows that weather shocks reduce women's educational attainment. Moreover, their study finds that when schooling is free of charge, and both marginal boys and girls are enrolled, a negative income shock has an adverse effect on the test scores of female students while boys are not affected. The results imply that households respond to income shocks not only be varying the access to schooling, but potentially modifying the amount of time resources provided to girls for schooling. A study in Madagascar shows that negative rainfall deviations and cyclones reduce the probability of attending school and encourage young men and, even more so, women to enter the workforce. The same study shows that less wealthy households are most likely to experience this school-to-work transition (Marchetta et al., 2019). Along the same line, evidence from an extensive study in Vietnam implies that households respond to income shocks produced by extreme precipitation by varying the amount of schooling and resources provided to girls, while boys appear to be sheltered from these reductions.[8]

Finally, adverse climatic events in childhood may divert girls away from joining the formal labor market in adulthood. Despite the achievement of gender equity in education in many lower-income countries, a gender gap still exists with respect to formal employment and the possible effects of climate change on human capital. Findings indicate that rainfall shocks experienced early in life have a long temporal effect by reducing the probability of formal sector employment for women but not for men. Other findings indicate that the gendered impact of rainfall shocks has differential effects on educational attainment and that shocks occurring in the first years of life are most important (Feeny et al., 2021).

4. Climate Change *Mitigation* and Human Capital

This section presents mitigation's effects on human capital through the direct and indirect channels described previously. Mitigation denotes the reduction of the net inflow of greenhouse gases into the atmosphere; and mitigation measures include technologies, processes, or practices that contribute to mitigation. Mitigation policies include subsidizing renewable energy technologies, introducing emission-reducing agriculture policies, or incentivising public transport commuting practices.

[7] However, unmarried men tend to be at greater risk than unmarried women. It appears that social isolation, more common among elderly men, may be a risk factor (Klinenberg, 2002).

[8] See also Duryea et al. (2007) for similar evidence from Brazil, and Jensen (2000) identifying equivalent dynamics in Côte d’Ivoire. In the latter case, the research describes school enrollment rates declining by between one-third and one-half and malnutrition doubling.

Mitigation actions have positive and negative effects on human capital accumulation, usage, and protection. Depending on contextual factors, policy design, and policy implementation, most mitigation policies are linked to co-benefits and adverse and possibly unintended side-effects. While reduction of greenhouse emissions will bring immense benefits in the aggregate and to many individuals, mitigation policies will also be disruptive and costly for human capital, at least in the short term, to some individuals and groups. Generally, the risk of any negative outcome is typically greater in contexts characterized by high poverty levels, and economic and social inequalities.

Although mitigation effects on human capital may be difficult to quantify, some attempts have been made to develop conceptual frameworks that can capture the positive and the negative human capital consequences of mitigation. The evidence-base, however, is still weak, due to data availability and to methodological constraints (Noy, 2022). However, there are case studies where careful analysis has uncovered some persistent positive and negative effects of mitigation that relate to diverse aspects of human capital (IPCC 2021; ILO, 2018; OECD, 2017). As countries try to prevent climate change, these policies have long-term goals. Therefore, some documented studies refer to potential effects that have not been realized yet.

Mitigation measures with the most visible socioeconomic impacts are policies that aim to increase the price of carbon-based energy sources and consequently decrease their usage. These include cap-and-trade systems, carbon taxes, and other mitigation policies where carbon pricing is implicitly embedded in other taxes and subsidies such as energy taxes on oil, gas, and coal products, tax credits for renewable energy projects, and policies to encourage renewable energy, biofuels, among others. Substituting low-carbon for high-carbon technologies and practices changes the nature and viability of many economic activities, with some industrial sectors and businesses shrinking or disappearing altogether and others emerging and flourishing.

Table 2. Climate Change Mitigation and Human Capital: Effects and Evidence

Mitigation

LIFECYCLE	DIRECT EFFECTS	INDIRECT EFFECTS
Prenatal and early childhood (-1 to 5)	++	++
	++	+
School-aged children (5-18)	++	++
	++	+
Youth and adulthood (18-60)	++	++
	++	+
Elderly (+60)	++	++
	+	+

Note: The degree of impact (represented in red) denotes the severity of climate change effects on human capital through the identified pathway, categorized as low, medium, or high. The strength of the evidence (represented in blue) reflects this report's evaluation of the quality, consistency, amount, and type of evidence, which is classified as limited, medium, or robust.

Direct effects: Health, Nutrition, and Wellbeing

Measures to mitigate the atmospheric concentration of warming climate-altering pollutants may significantly benefit human health and well-being across every life cycle stage (Table 2). Improved air quality, and associated health effects, are the co-benefit category dominating the mitigation literature. Although there is not much evidence on the effects of mitigation, there are studies that are able to calculate the potential benefits of improved air quality. Improved air quality is especially beneficial for infants and children. Infants are most sensitive to respiratory hazards because of their lower body weight, higher levels of physical activity, and still-developing lungs. Perera et al. (2020) assess public health impacts associated with changes in air quality due to the Regional Greenhouse Gas Initiative (RGGI) in the United States. Their results indicate that the RGGI has provided substantial child health benefits. Moreover, those health benefits had significant estimated economic value. Another study led by the United Nations Environment Programme (UNEP) and World Meteorological Organization (WMO) on black carbon emissions and tropospheric ozone emissions found that if mitigation measures were implemented on a global scale, they would have substantial benefits for health in terms of premature deaths and mortality for all ages (Amann et al., 2011).

A study simulates the co-benefits of global GHG reductions on air quality and human health using a global atmospheric model and consistent future scenarios via two mechanisms: reducing co-emitted air pollutants and slowing climate change and its detrimental effect on air quality. Results showed potential reductions of 1.3 million premature deaths by 2050 with avoided costs of premature mortality many times those of the estimated cost of abatement (West et al., 2011). Along the same lines, several studies have found that the benefits from lower air pollution alone could more than offset the cost of mitigation in many regions, especially before 2030 (Shindell et al. 2012; Shindell 2015). They concluded that abatement of particle emissions, including black carbon, represents an opportunity to achieve both climate mitigation and health benefits.

There is growing recognition that implementation of decarbonization policies in urban transport has additional near-term health co-benefits through increased physical activity. Co-benefits and corresponding cost reductions are often not considered in decision processes, likely because they are not easy to quantify. Wolkinger et al. (2018), analyzes three mobility scenarios in three larger Austrian cities and show substantial GHG emission reductions, increased physical activity, and reduced annual direct and indirect health costs. The study concludes that higher levels of physical exercise and reduced exposure to pollutants due to mitigation measures substantially decrease morbidity and mortality. Another study by Jensen et al. (2013) also concluded that, among various strategies for achieving UK 2030 climate targets, increased active travel gives significant positive health co-benefits.

Decreases in air pollution from transport can also reduce existing health inequalities, especially in large cities that presently struggle with high levels of air pollution that is concentrated in more disadvantaged areas. Evans et al., (2002) provide an overview of data indicating that income is inversely correlated with exposure to suboptimal environmental conditions such as ambient and indoor air pollution. The most significant air quality benefits will therefore accrue primarily to lower-income households, who are most likely to live in locations affected by poor air quality from road transport (Pratt et al., 2015).

Overall, have not identified any adverse (unintended) human capital cost from mitigation that is directly related to health and wellbeing. It seems that any negative implication for mitigation for human capital is only conveyed indirectly, through markets and economic systems.

Indirect Effects: Economic Systems and Infrastructure

The economic dynamics generated by climate change mitigation policies point to two possible dynamics. Relatively direct effects on human capital include job and income losses in sectors that are (slowly) becoming obsolete (e.g., oil drilling) and whose human capital is therefore becoming obsolete as well. Indirectly, the need to reduce training for obsolete jobs, and to increase training capacity for the new type of jobs required for the energy transition involve a lot of expenditure on human capital (and thus potentially reducing spending on human capital elsewhere).

Various types of mitigation policies can potentially benefit human capital. For example, new opportunities for income generation in deprived areas through participation in new markets and strategic location of large-scale renewable energy systems in areas with limited employment opportunities (e.g., Sacchelli, 2016). The transition to a low-carbon economy may create new jobs in renewable energy generation systems that can be realized cost-efficiently due in part to rapidly falling costs of renewable energy (IRENA, 2020).

However, negative impact of mitigation policies may also arise with adverse distributional effects. Estimates of the aggregate economic costs of mitigation vary widely and are very sensitive to model design and assumptions and the specific scenarios being considered (IPCC, 2014). For example, mandates and taxes associated with mitigation are increasing the cost of some essential (low price elasticity) goods, such as food, energy, or transportation (Markkanen and Anger-Kraavi, 2019). These costs affect most severely the poorest and most vulnerable members of society who spend a larger proportion of their income on such goods and services (Jennings, 2015). Low-income households will be negatively affected the most from the transition as they spend a more significant share of income on energy-intensive products and lack access to potential substitutes. As such, the human capital implications will also manifest themselves less equally.

The consequences of the green transition also manifest in the labor market. Yet, the evidence on the employment implication of mitigation policies is limited and inconclusive. Some studies predict slight increases in employment (Chateau and Saint-Martin, 2013), and other studies identify some decreases, showing, for example, that high in-work poverty in the industries of interest, and especially in middle-income countries, is often associated with low skills and an insufficient reach of social protection mechanisms (Malerba and Wiebe, 2021)

Carbon pricing will impact the labor market in the fossil fuel industry and other sectors of the economy with uneven effects across regions. Job losses will tend to be concentrated in carbon-intensive industries and spatially in the communities where such industries are concentrated (Campbell and Coenen, 2017; Just Transition Centre, 2017). Indeed, much of the relevant literature urges particular attention to the spatially varying distributional effects of the energy transition (Green and Gambhir, 2020). As is the case globally, the effects of decarbonization within countries will also be unevenly distributed between and within regions.

Adjustments to the energy infrastructure may cause structural unemployment. Laid-off workers may not immediately find a new job in the renewables industry as they have different abilities, and the jobs have different requirements. Matching old workers with new jobs will take time and may not be feasible for everyone. Limited short-run flexibility of real wages can further contribute to fluctuations in output, employment, and unemployment.

In this sense, mitigation of climate change will require workers to be skilled and reskilled, potentially affecting the retirement decisions of those close to retirement age. Given the constant necessity to adapt skills to the new circumstances and needs created by the energy transition, the existing human capital is bound to depreciate faster. *Ceteris paribus*, a higher depreciation rate will lead to a lower optimal level of investment, and thus potentially reducing the overall amount of human capital being developed. Furthermore, these mechanisms will also induce earlier retirement, as the need to retrain will at some point in the life cycle become too costly to undertake. The rationale behind this is that for older adults who are close to retirement age, the costs of investing in new skills are higher than the benefits, given that they will soon need to retire anyway. In this sense, the investment is unattractive, and they would rather retire earlier than commit to such an investment. Then, the higher depreciation rate will induce the earlier retirement of older workers, especially for workers ages 60 or older.

A co-benefit of mitigation policies is that they may improve households' financial circumstances. The positive impacts are most significant when energy efficiency improvements are implemented in fuel-poor homes or households that previously underutilized heating (or cooling) services due to financial and budgetary constraints. Improved ability of such households to afford a comfortable indoor temperature can reduce health and other social inequalities by improving living conditions and household finances, leading to better educational performance, and improved overall wellbeing (Markkanen and Anger-Kraavi, 2019). Of course the opposite may also be true, and sustainable energy may become more costly.

Mitigation policies addressing the aviation sector's GHG emissions could significantly impact travel costs and tourist and transport mobility. Rising oil prices can impact the aviation sector significantly, and those costs are generally passed on to the traveler or freight customer. Such an effect is particularly salient for long-haul destinations, potentially affecting tourism development and wealth transfers to tourism-dependent developing nations. Some destination countries (i.e., Caribbean islands, Australia, New Zealand, and Pacific islands) have expressed concerns that the inclusion of aviation in climate mitigation policies could cause visitor numbers to decline because of associated increases in travel costs. Although not conclusive, evidence measuring the effects of mitigation scenarios on tourism does not represent a substantial threat to tourism development (Mayor and Tol, 2007; Gössling et al., 2008; Rothengatter, 2009).

Efforts to mitigate climate change will affect agricultural prices and consequently food consumption. There are rising concerns that climate policy could conflict with food security objectives: several studies find meeting climate change mitigation objectives and at the same time producing enough to feed 10 billion people by 2050 may be challenging (Godfray, 2010; Smith and Gregory, 2013). A more recent study by Havlík et al. (2015) examining the food security impacts of climate change mitigation policies found that – depending on how mitigation policies are implemented for the agricultural sector – the negative effects of mitigation could be even worse than the negative effects of climate change itself in the medium term. This study shows agricultural commodity prices would increase because of the pricing of carbon. Crop prices would increase just moderately by 4% and livestock prices by 7% on average. The livestock price increase would be particularly high in regions with GHG emission intensive production systems. If this was indeed to transpire, it would involve clear implications of human capital accumulation.

Mitigation requirements in agriculture could limit the potential for increasing and improving food production. Climate change mitigation measures have two significant direct effects on food consumption and the risk of undernutrition: Competition for land between food crops and energy crops (for bioenergy) may increase the costs of producing food. In addition, the costs associated with mitigation measures taken to reduce emissions may lead to higher production costs (Hasegawa et al., 2015). The IPCC (2019) concludes that large-scale mitigation at the global scale can reduce the availability of land for food production, with implications for food security. Modeling simulations show that mitigation policies that do not consider food security could have a more significant impact on prices than climate change (Hasegawa et al., 2018).

Applying a uniform carbon price across geographic regions and economic sectors may have inequitable effects on countries' agricultural competitiveness and food availability. The cost-efficient distribution of mitigation efforts across regions and sectors is typically calculated using a global uniform carbon price in integrated assessment models. Empirical evidence suggests that different countries face quite different incentives for emission pricing (Edenhofer, 2015). Regions with poor productivity and consequently higher GHG emission intensity would likely experience a significant increase in agricultural commodity prices. So that uniform carbon price would lead to substantial impacts on food affordability. For example, Halvik et al., (2015) show that a mitigation policy to stabilize climate below 2°C uniformly applied to all regions as a carbon tax would also result in a 6 percent reduction in food availability by 2050 and 12 percent reduction by 2080.

Technological barriers and training costs might dissuade the elderly population from pursuing a career in the new low carbon economy, thus forcing them to retire earlier from the labor market. An unexpected change in the rate of technological change could induce older workers to retire sooner because the required amount of retraining could be an unattractive investment (Bartel and Sicherman, 1993). For older adults who are close to retirement age, the costs of investing in new skills are higher than the benefits, given that they will retire soon anyway. In this sense, the investment is unattractive, and they would rather retire earlier than commit to such investment. Given that both with climate change and with technological change it is necessary for workers to adopt new skills, it can be expected that in both cases workers close to retirement age choose to retire earlier.

5. Climate Change *Adaptation* and Human Capital

Adaptation refers to the process of adjustment to actual or the expected future climate and its effects in order to moderate its harm or exploit its opportunities (IPCC, 2021). In this sense, adaptation policies aim to reduce exposure, reduce vulnerabilities, or increase adaptive capacity to climate hazards and thus protect people and assets. These adaptation policies can be undertaken both by individuals and households (e.g., adopting new skills, purchasing insurance, or migrating), or at larger scales by communities, sometimes in actions instigated by government at its various levels (a city investing in a managed retreat program, or even a central government changing building codes and zoning laws).

This section will discuss the sparse evidence on adaptation policies and their consequences for human capital. Unlike the direct impacts of climate change on human capital, which can be categorized into stages in life and channels, adaptation policies are often cross-stages and cross-channels. This is related to how such decisions are often made at the household level, affecting mostly only people within the household, or at the other end of the size spectrum, by governments, and thus affecting all of a jurisdiction's residents. For example, when a household decides to migrate, the human capital of all members will be affected through different channels. Consequently, to avoid being iterative in this section, we will organize the evidence by topic rather than by channel. It is noteworthy that we will still mention differential impacts by stage of life and through different channels in each topic. The main topics discussed in this section will be: (1) migration, (2) family planning and fertility, and (3) adaptation in agriculture.

Table 3. Effects of Adaptation to Climate Change on Human Capital and strength of the evidence across the life cycle.

Adaptation

LIFECYCLE	DIRECT EFFECTS	INDIRECT EFFECTS
Prenatal and early childhood (-1 to 5)	+++	++
	++	++
School-aged children (5-18)	++	++
	++	++
Youth and adulthood (18-60)	++	++
	++	++
Elderly (+60)	+	+
	+	+

The level of impact (red color) indicates the degree of the effects of climate change on human capital (low, medium, high). The strength of the evidence (blue color) indicates the assessment of the evidence's type, amount, quality, and consistency (limited, medium, robust).

5.1. Migration

Diversifying household members' residence is an adaptation strategy with implications for the protection of human capital. Diversifying household members' place of residence can also assure consumption smoothing in the event of climatic events, thus strengthening members' ability to protect their human capital. Some households opt to send some members to a location farther away as an alternative to ensure against consumption or income risk. For instance, Dillon et al. (2011) find that households exposed to higher temperature increases are more likely to have at least one household member sent away. Similarly, Gröger and Zylberberg (2016) show that non-migrant households in Vietnam sent household members to different locations in the aftermath of a typhoon. Based on evidence from southern India, Rosenzweig and Stark (1989) further argue that marriages with partners living a certain distance from the rest of the family can function as a climate-related consumption smoothing strategy. Given that income from agriculture is often spatially correlated due to similar climatic conditions, investing in longer-distance marriages may be a successful strategy to minimize risk and protect household members' human capital.

The evidence suggests that disasters and weather anomalies induce both domestic and international migration, particularly in lower-income countries. Both internal and external migration can be a significant tool in adapting to extreme weather events and other climate change impacts. Furthermore, short- and long-term migration can also be a reaction to a sudden change in the environment and be seen as a coping mechanism, especially when other adaptation strategies are unavailable, ineffective, or too costly (Berlemann et al., 2017).

Given the projected increase in frequency and intensity of disasters due to climate change, it is relevant to analyze their impacts on migration. One stream of the literature is related to agricultural and natural resource-dependent households in low-income countries, for which climatic conditions are essential for subsistence, as they often need to grow crops and produce their food. For them, even without an extreme disaster, changes in temperatures or rainfall threaten livelihoods and may induce them to migrate. For instance, evidence from South America shows that both positive and negative temperature shocks tend to increase inter-provincial migration (Thiede et al., 2016). Roeckert and Kraehnert (2022) identify similar dynamics in Mongolia, while Berlemann and Tran (2020) identify differences in the duration of internal migration associated with different types of extreme weather events.

Extreme weather events increase migration from the affected regions. Feng et al. (2010) studied the impact of climate-driven crop failures in Mexico and found that, in this case, international emigration increased due to below-average rainfall. Gray and Mueller (2012) study the effect of rainfall on migration in rural Ethiopia and find robust evidence of increased labor migration in response to rainfall deficits. Moreover, they find that land-poor households are the most likely to migrate. Báez et al. (2017) find that younger individuals in Northern Latin America and the Caribbean are more likely to migrate in response to hurricanes and droughts. Similarly, Murray-Tortarolo and Salgado (2021) find that the migration of low-income rural farmers from Mexico to the United States tripled during drought years. These weather anomalies are expected to be more frequent due to climate change, so further migration pressures should be expected.

In some cases, migration may not be permanent, as workers move seasonally in response to extraordinary seasonal weather anomalies. Evidence from India shows that, although temporary migration can be observed even in non-drought years, during a drought it increases significantly, and is the most essential coping and adaptation strategy in a village in the Coastal Indian state of Odisha (Jülich, 2011). Similarly, Jessoe et al. (2018) find that individuals in Mexico are less likely to work locally in years with a high occurrence of extreme heat. According to their findings, a medium emissions scenario implies that increases in extreme heat may increase migration by 1.4 percent. Indeed, extreme heat increases domestic migration from rural to urban areas and international migration to the US, especially among those living closer to the border.

In many dimensions, climate change-driven migration is similar to conflict-induced and economic migration, with the latter being mainly driven by poverty and lack of economic opportunities. First, all these migrants may suffer from physical or psychological trauma due to the experienced events forcing them to migrate. Second, disasters, like conflicts, may induce destruction or expropriation of assets, including crops, meaning migrants may face significant adverse declines in wealth before migrating. Third, the location they migrate to may not be optimal, especially if they migrate as an emergency response to a sudden-onset event, or if their migration paths are restricted (as is almost always the case). Their economic and political status in host communities is frequently uncertain (more uncertain than for recognized refugees). Due to these similarities across all types of migrants, the knowledge about the experience of economic and conflict-displaced migrants is also relevant to environmental climate change migrants.

Experiences from civil wars, disasters, and economic crises show that migration has various consequences for the host communities and migrants affecting human capital. First, immigration has, in many cases, a negative impact on wages. Although there is not much evidence of lowered wages for environmental migrants specifically, one may argue that migrants could suffer from low wages related to the lower-quality jobs they may need to take after moving. One reason behind the mismatch could be that the destination communities may not be able to create sufficient labor demand to match the increased supply.

Various causes may cause that migrants take jobs that do not match their skills to earn a livelihood. For example, due to insufficient labor demand in some locations, migrants may end up in suboptimal locations such as peri-urban areas, where job quality could be lower. Other barriers such as language or the lack of legal work permits may orientate migrants towards informal, manual, low-quality jobs, which are also usually lower-paid. Additionally, international, and even domestic migrants may suffer employment discrimination in their new communities, forcing them to obtain lower-quality jobs. These barriers may induce a lower probability of employment or a lower probability of high-quality jobs, reducing their earnings. Again, there is little quantitative evidence for these channels.

There is, however, substantial evidence of the adverse effects on wages in host communities, particularly for local workers in informal sectors competing with the newcomers. For instance, Maystadt and Verwimp (2014) show that, due to the Hutu-Tutsi conflict in Rwanda and Burundi, agricultural workers in Tanzania experienced increased competition from refugees, while agricultural producers could take advantage of the refugee inflow, which resulted in lower wages. During such conflict, Ruiz and Vargas-Silva (2016) also found that employment in general fell and household work increased.

Immigration changes the country's labor market, mainly affecting low-skilled workers. The influx of Syrians to Turkey showed that Turkish workers in regions with a higher share of refugees experienced a stronger shift from informal to formal employment (Tumen, 2016). This can be attributed to Syrian workers obtaining jobs in the informal sector, displacing low-skilled local workers (Del Carpio and Wagner, 2015). Similarly, increased competition between internally displaced people and host workers in Colombian cities generated lower wages for the host community, especially for those low-skilled and employed in the informal sector (Caruso et al., 2021; Morales, 2018). In this sense, a large migration influx related to climate change could negatively affect local low-skilled workers.

Migration may also change labor market conditions and children's work time. The migration of some family members withdraws human capital and labor from the sending household, a loss that may be compensated for by increasing child labor in the home or in wage employment (Mendola, 2016). The evidence shows that child labor can increase due to decreased household welfare in host and migrant communities.

Furthermore, the price of accommodation may increase in cities receiving a large migration influx. Depetris-Chauvin and Santos (2018) find such increases in cities with more internally displaced people. However, the impact was not homogeneous; it is low-income accommodation whose prices increased, meaning that the most vulnerable –both local and migrants– were most heavily affected, with their real incomes declining the most. These increases in housing prices also can potentially lead to intra-communal conflict related to increased inequality (Becker and Ferrara, 2019). Additionally, a higher share of income allocated toward housing may imply a lower share of income allocated to food or education. All of these dynamics may lead to deterioration in the accumulation, use, and preservation of human capital.

Finally, and in contrast to all the negative channels outlined above, environmental migrants moving to cities can benefit from increased education and other opportunities. There are some cases that identified population movement after a disaster that brought longer-lasting gains. This could be interpreted as people being stuck in locations where they could previously not realize their full economic potential (Deryugina et al., 2018). For example, after the eruption of the volcano in Westman Islands, migrants leaving the island had attained 3.5 years of additional higher education than those unaffected (Nakamura et al., 2018). In sum, although there are adverse effects in terms of human capital for displaced people, there are exceptions in which some, especially the young, benefit from their displacement in the longer term through the availability of better opportunities in their new host communities.

5.2. Family Planning and Investments in Human Capital

As noted earlier, climate change-related weather events increase morbidity and mortality in early childhood, especially in low-income countries. The increased morbidity and mortality associated with climate change may cause parents to modify their family planning. Parents can either choose to have fewer children or invest more in each of them, possibly to offset the negative impacts of climate change. Alternatively, they can decide to have more children and thus invest fewer resources in each child (Millimet and Wang, 2011; Becker, 1960; Li et al., 2008). Historically, when observing reductions in child mortality, families usually made "replacement decisions" regarding children (Aksan, 2014). In progressively safer environments, they chose to have fewer children and invest more in developing the human capital of each one. This means that parents may begin to have smaller families and devote more to each child's education, nutrition, and health (Kalemli-Ozcan, 2008). This may explain why lower child mortality rates are closely linked to fewer children (lower fertility) and more educated ones (Soares, 2005).

However, climate change-related increases in mortality may induce parents to do the opposite - have more children and inevitably invest less in each of them, affecting their accumulation of human capital. Cross-sectional evidence suggests that this scenario is possible; though there is no time-series data that can demonstrate this happening. For example, diarrhea, malaria, and other diseases in Africa are frequent, child mortality remains high, and childhood morbidity and mortality increase uncertainty about child survival. Parents perceive a high risk for their child's survival and development. Consequently, this risk dampens expected returns to human capital investment, and therefore having many children remains possibly a more attractive possibility than investing more in fewer children (Behrman and Rosenzweig, 2001). In short, more frequent disasters may lead parents to a trade-off which is adverse to human capital accumulation. The subsequent effects can have long-lasting consequences for their children's livelihoods, health, education, and well-being (Psacharopoulos and Patrinos, 2018, Alderman et al., 2006).

5.3. Adaptation in Agriculture

The agricultural sector will be one of the most affected by climate change; thus, adaptation in the sector will be inevitable. In changing environmental conditions, farmers will likely change how they farm to minimize losses and take advantage of new opportunities (Webb et al., 2017). Farmers must decide what crops to grow, as different crops are differently suited for the expected realizations of temperatures and precipitation levels. They further need to determine when to plant and harvest those new crops, which inputs to use in crop production (seeds, fertilizers, and pesticides), and whether and how to rely on irrigation.

Evidence suggests that these decisions regarding crop growth are climate-sensitive, and farmers will need to adapt their activities to climate change. In South-East Asia, Webb et al. (2017) find that farms which are 1°C warmer than the mean are 6.2% more likely to grow rice, 1.7% more likely to grow oilseed, 1.7% more likely to grow fruits, and less likely to grow vegetables, maize, beverage and spice crops, legumes, and rubber. Similarly, they find that farms with 1 cm more monthly rainfall than average are more likely to grow rice, vegetables, and fruits but less likely to grow maize. Similar choice architecture can be found in other regions – for example, in China (Wang et al., 2010). In South America, farmers choose fruits and vegetables in warmer locations, wheat and potatoes in cooler locations, rice, fruits, potatoes, and squash in wetter locations, and maize and wheat in dryer locations (Seo and Mendelsohn, 2008). Therefore, changing climatic conditions are likely to induce changes in planted crops.

Irrigation is also climate-sensitive across regions. Although most analyses usually consider irrigation as exogenous, in the context of climate change, farmers react to climatic conditions such as high temperatures and low levels of precipitation by adapting their usage of irrigation. In Latin America, summer precipitation and winter temperature are significant determinants of whether irrigation is chosen (Seo and Mendelsohn, 2008). Not surprisingly, irrigation is an effective adaptation against reductions in rainfall and temperature increases, provided sufficient groundwater is available.

Planting and harvesting dates are also subject to seasonal shifts due to climate change. Evidence from Europe (Moore and Lobell, 2014), Burkina Faso (Waongo and Kunstmann, 2015), and South-East Asia (Webb et al., 2017) show the climate sensitivity of the choice of planting, growing, and harvesting dates. Farmers in Bangladesh, Indonesia, Sri Lanka, Thailand, and Vietnam grow their crops for an average of 3.5 months. They have, on average, two of these growing seasons each year (up to 3.4 growing seasons if they irrigate). In addition, farmers choose planting dates that allow plentiful rainfall in the first two months of their growing season and less rainfall closer to harvest. For this reason, changing weather conditions could affect planting dates, and more uncertainty around weather conditions makes it more difficult to choose those dates optimally. There is evidence that farmers do not plant when there is a risk of flooding, and that they plant in months with high temperatures (Webb et al., 2017). With more temperature and precipitation variability, farmers lose a lot of the agricultural knowledge they already possess, and now need to make crucial decisions with less knowledge and experience about the consequences of these choices.

Finally, the use of inputs is usually also climate sensitive. Changes in climatic conditions could lead to changes in inputs such as water and fertilizer. In some cases, farmers may favor variability-reducing inputs and production techniques or those that minimize the likelihood of adverse outcomes rather than increase the expected amount of crop. This can result in lower incomes through risk reduction strategies such as using more labor or less fertilizer than optimal to reduce losses in bad times (Lamb, 2003; Dercon et al., 2011), or limiting production to cut potential losses once weather information has been learned. In sum, climate change induces more volatility and potentially lower expected crop amounts. This is particularly important in the absence of available ex-ante risk management strategies.

It is incontrovertible that, *ceteris paribus,* more adaptation is preferable to less from a human capital perspective. The higher productivity associated with these adaptation options allows for more income and more available resources for investing in human capital. For health and nutrition, increased food security due to adaptation allows children and adults to be healthier and avoid the consequences of malnutrition. In this sense, adaptation policies bring better human capital outcomes. However, there are also adverse consequences to human capital from adaptation, which need to be recognized, and potentially countered, with a particular emphasis on required but difficult to implement adjustments in agricultural work.

6. Lessons and Knowledge Gaps

Climate change poses many risks to societies, economies, and local communities. The risk it poses to human capital, as distinct from the risks it poses to physical or financial capital, is evaluated here. This survey presents robust evidence that shows climate change can significantly affect critical human capital outcomes with the damage it causes, and through adaptation and mitigation, across the life cycle, and through several channels.

The documented evidence shows that these effects vary in intensity along the life cycle and that the impact of high temperatures, heavy precipitation, droughts, and other climatic events have persistent, adverse, and long-lasting effects on human capital. These effects refer not only to the direct and indirect impacts on human capital, but also to the effects of mitigation and adaptation policies which aim to respond to the threat of the changing climate. More overlooked, the document highlights that while mitigation and adaptation to climate change are clearly beneficial overall, they also have significant costs for specific sectors and groups in society. Ignoring these costs only makes both adaptation and mitigation more difficult to implement, and potentially more damaging to human capital.

The document also identifies knowledge gaps and a continuing need for analysis on the effects of climate change on human capital. The review of the evidence shows that various effects are unclear, are not yet quantified, and often lack a robust evidence base. Particularly, more research is needed to evaluate the actual costs of mitigation and especially adaptation actions and the effectiveness of policies to alleviate these effects. However, this is not an argument for inaction. By comparing to other similarly radical transitions, we can identify the failures to prevent the human capital dislocation that unfortunately can accompany such social transitions and their adverse implications.

Globalization exemplifies how beneficial (in the aggregate) change is, while it can also negatively affect some communities and households if policies to protect them are not implemented effectively. Without appropriate actions to promote better outcomes for those adversely affected, the change can cascade into significant backlash, loss of political support, and eventually retrenchment and reversal of reforms that, in the aggregate, could be potentially very beneficial. It would not, we think, be controversial to argue that this is exactly what happened with globalization.

Preventing these adverse effects should therefore be a focus of a people-centered approach in policy development that supports the most exposed and vulnerable to climate change. As countries start from different points and have different emission levels, they therefore need differentiated actions and support. Poorer countries, regions, and communities within countries, are among the most affected by climate hazards but are often also the most adversely affected by the implementation of adaptation and mitigation policies. Past transitions show transition-related reforms have major impacts on the poor. Policy investments must not only prioritize a meaningful and the most cost-effective reduction in GHG emissions, but need to be aware of the potential adverse impacts on the most vulnerable. Those that are the most vulnerable include both those vulnerable to extreme weather impacts, but also those vulnerable to the transition or adaptation policies. The human and economic costs of these changes thus require policy designed specifically for displaced workers, for adversely affected communities affected by adaptation (e.g., migrants), and low-income vulnerable households more generally.

Finally, human capital also has the potential to play a fundamental role in driving climate change policy. The capacity to adapt to climate change, as well as the effectiveness of mitigation actions, is strongly interrelated and indeed determined by human capital. In this sense, laying out priorities and investing in people-centered policies is an opportunity that allows for a virtuous cycle that delivers positive outcomes on both climate change and human capital.

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