Child labour in agriculture: A response to climate change?*

Mathias Weidinger†

March 10, 2021‡
First version: November 2020

Abstract

Anthropogenic climate change does not only pose a challenge to agriculture in developing countries in general but to the livelihoods of the millions of children actively involved in that sector specifically. Not withstanding the urgency conveyed by the facts, economic theory is not currently geared towards characterising the effects of a structural change in the local climate inputs to agriculture on agricultural child labour. Merging two strands of theoretical literature, from Environmental Economics and Development Economics, this paper introduces a simple household decision model of child labour supply under climate change. To take the model to the data, I combine a household panel from Nigeria with geo-coded weather records and estimate an empirical dose-response function.

*Acknowledgement goes here.
†Maastricht University and UNU-MERIT, `m.weidinger@maastrichtuniversity.nl`
‡The latest version of this paper is available at `mathiasweidinger.com`

1 Introduction

Globally, nearly one in ten children are subjected to child labour, which rises to nearly one in every five children in Africa. On any given day in 2016, 152 million children aged 5-17 were in some form of child labour; half of them worked under hazardous conditions (ILO, 2017). The consequences of such wide-spread child labour are well-understood:

> Child labour can result in extreme bodily and mental harm, and even death. It can lead to slavery and sexual or economic exploitation. And in nearly every case, it cuts children off from schooling and health care, restricting their fundamental rights and threatening their futures (UNICEF, 2020).[1]

Unfortunately, Child labour is notoriously difficult to regulate. This is in part due to its informality: Most child labour is unpaid and takes place far off the formal labour market, on family farms or in family owned enterprises. Consequently, the compliance costs of anti child labour legislation are so high that even where such laws are in place, enforcement tends to be lax or, all too often, entirely absent.[2] Despite sustained international efforts to eliminate it, child labour decreased by only one percent in 2008-2012 and ILO (2017) estimates that at the current rate of progress, 121 million children will still be working in 2025.[3]

Disaggregating the data reveals that 59 per cent of working children in Africa are between 5 and 11 years old and that almost nine in ten of them work in agriculture - 61.4 million children in absolute terms. The uniquely high concentration of child labour in agriculture - particularly in Sub-Saharan Africa (SSA) - begs a question: What happens to these children if agriculture becomes an increasingly unstable sector? Do they work more or less hours on average? Does their work become more or less hazardous? How is

[1]For a recent review of the adverse health outcomes of child labour, see Ibrahim et al. (2018).

[2]Note that this is not necessarily due to government negligence. Most countries with high rates of child labour also suffer from limited fiscal capacity and, consequently, prohibitively small budgets.

[3]The International Convention on the Rights of the Child (ICRC) recognises the right of every child to be protected from economic exploitation and from performing work that is hazardous or harmful to their health and development or that interferes with their education. The ILO conventions on minimum age for admission to employment (no. 138, ratified by 173 countries) and on the the elimination of the worst forms of child labour (no. 182, ratified by 187 countries) are binding international agreements to this effect. Targets 8.7 and 16.2 of the United Nation's Sustainable Development Goals additionally target child labour, pledging to end it in all its forms by 2025.

their overall welfare affected? These concerns bear unprecedented relevance in the wake of anthropogenic climate change.

There is mounting evidence that the human-induced accumulation of Green House Gases (GHG) in the earth's atmosphere has caused the global climate to change and will continue to do so in the coming centuries (Pachauri et al., 2015). Many new record highs suggest that the earth's mean temperature is increasing. Munasinghe et al. (2012), for instance, show that the frequency of extremely high temperatures across the global landmass increased tenfold between the beginning of the twentieth century and 1999–2008. The high frequency of new record lows over the same period suggests that climate change affects both the mean and the variance of temperature (Auffhammer and Schlenker, 2014). As a consequence, climate change brings with it a persistent rise in the probabilities of (seemingly antithetical) extreme weather events, notably droughts and floods, snow storms and heat waves, cyclones, and hurricanes (Pachauri et al., 2015). These changes in the natural environment profoundly alter the playing field for human economic activity on planet earth.

It is of course true that climate change affects different regions in different ways. This heterogeneity has inspired some to speculate, whether the negative impacts experienced in some areas could be offset by positive effects elsewhere[4], or be it in strictly economic terms. Tol (2009), for instance, notes that "[a]lthough the world population is concentrated in the tropics, where the initial effects of climate change are probably negative, the relatively smaller size of the economy in these areas means that gains for the high-income areas of the world exceed losses in the low-income areas". He later qualifies this statement, adding that, in the long term, warming above 1-2 degrees will likely have negative total effects. But even for the short-term, arguments like Tol's ought to be read with some scepticism. They are not inherently incorrect, but their accounting method entirely ignores the tremendous

[4]For instance, while agricultural yields are likely to decrease in SSA, there is some conjecture that large parts of northern Eurasia, which are currently covered by permafrost, could become arable as temperatures rise. Moreover, an elevated concentration of atmospheric CO_2 reduces "water stress" in plants and may make them grow faster. This phenomenon is known as "CO_2-stimulation" in the agriculture literature and its beneficial effect on crop yields remains understudied and, hence, unincorporated in most projections (e.g., in Schlenker and Lobell, 2010).

distributional consequences of climate change (and indirect economic effects that stem from them).

The world's richest countries, which are predominantly situated in the global north, are responsible for almost eighty percent[5] of GHG emissions in 1850-2011 and high income countries continue to emit the most GHGs by far[6] (Ritchie and Roser, 2017). Due to their location, high income countries also experience more benign effects of climate change compared to their more vulnerable counterparts further south, which face the harshest consequences. Intensified temperature extremes, precipitation anomalies, and natural disasters are all projected to disproportionately afflict Latin America, South Asia and the Pacific, and Sub-Saharan Africa. Together, their populations account for the vast majority of humanity. Thus, Climate Change exacerbates existing global inequalities and there is an argument to be made for distributional considerations beyond simple aggregate cost-benefit analysis. Distributional analysis will prove hugely relevant to migration policy, International cooperation, and conflict-prevention efforts - not to mention global solidarity.

In SSA alone, the effects of climate change are responsible for at least 1,000 deaths, 13 million people seriously afflicted[7], and 520 USD million in direct economic damages since 2000. One-third of the world's droughts occur in SSA, and the frequency of storms and floods is growing fastest in this region (IMF, 2020). Agricultural yields, meanwhile, are projected to fall significantly for the continent's four most important food crops: by 22 percent for maize, 17 percent for Sorghum, Millet and Groundnut, and eight percent for cassava (Schlenker and Lobell, 2010). Similar negative impacts have been projected for major cash-crops like coffee (Craparo et al., 2015)[8] or cocoa (Boeckx et al., 2020). These findings place agriculture at the center of climate vulnerability, and with it the millions of children working on farms throughout the world.

---

[5]The percentage is even higher when accounting for final consumption of goods, since great part of GHG emissions in low and middle income countries stem from the production of export goods, predominantly destined for high income countries.

[6]Note, however, that in terms relative to 1990 most high income countries now have lower annual growth rate of emissions whereas lower and middle income countries have increased their emissions substantially.

[7]This includes individuals who were injured, left homeless, food insecure, or lacking water and sanitation.

[8]For contrasting findings, based on CO_2-stimulation effects, see (DaMatta et al., 2019).

Even so, there is virtually no literature investigating the implications of these negative effects for child labour. The little empirical evidence there is displays three common flaws: limited data, misspecification, and a lack of theoretical underpinning. These shortcomings and the policy-relevance and urgency[9] of the child labour debate provide a clear motivation for further research. To narrow the gap, this paper is dedicated to analysing the effects of a progress in climate change on the prevalence of child labour in agriculture, as well as their implications for household and children's welfare.

Following a detailed overview of the literature in section 2, section 3 extends the economic theory of child labour to account for a sustained shock to household production due to climate change. Section 4 outlines the empirical problem and introduces an econometric framework to solve it. The methods used mend the shortcomings noted in the literature; a longitudinal data set from Nigeria (2010-2019) is combined with geocoded weather data from suitable ground level stations, supplemented by satellite-based estimates. The findings drawn from this analysis are discussed in section 5. Section 6 identifies actionable policies and concludes.

2 Literature

The topic at hand lies at the intersection of various strands of literature: Development and Labour Economics have provided some models of Child labour. Environmental and Resource Economics feature a relatively recent and fast-growing literature on the economic effects of climate change. Lastly, Agronomy has long studied the effects of weather shocks on agricultural output. This section offers an overview of the first and the second of these fields, subsuming the third within the more recent climate studies, which draw heavily from it.

[9] Given the proximity of the 2025 deadline scoped by SDG 8.

2.1 Child Labour

Child labour appears early as a topic in the economics literature. Among those who discussed its prevalence in Europe during the Industrial Revolution were Smith, Malthus, and Marx.[10] About a century later, the inception of human capital theory (Mincer, 1958; Schultz, 1961; Becker, 1964) fundamentally transformed the research agenda in labour economics and, as a corollary, gave some impetus to the study of child labour (see e.g. Rosenzweig and Evenson, 1977). The seminal contribution by Basu and Van (1998) eventually launched an enduring proliferation of the literature on child labor (Edmonds, 2007) in both theoretical and applied economics.[11]

Child labour is commonly modelled as a product of a constrained optimization exercise, undertaken as if each household were one collective decision maker. In practice, this implies that benevolent[12] household heads take decisions for the entire household in a nearly utilitarian fashion.[13] Basu and Van (1998) proved so influential because they formalized two long-held conjectures in axioms that became the bedrock of child labour theory.

The first of them, termed the 'luxury axiom', characterises parents' preferences over child labor as lexicographic: child labor occurs if and only if families cannot cover their subsistence needs without it.[14] This characterization of preferences would imply a strictly negative relationship between household income and the amount of child labour supplied by a household - a testable hypothesis for which Basu and Van (1998) have drawn substantial criticism (see e.g. Edmonds and Schady, 2012). Most notably, Bhalotra and Heady (2000, 2003) observe that children of land-rich families are often more likely to be in work than those of land-poor households.

[10] With the exception of Malthus, the early economists viewed children as investment goods. Marx, in particular, remarked that "all family ties among the proletarians are torn asunder, and their children transformed into simple articles of commerce and instruments of labour" (Marx and Engels, 1848).

[11] for a recent overview, see the dedicated volume by Posso (2020).

[12] On the credibility and extent of such benevolence and its implications, see Bhalotra (2002).

[13] Nearly because child leisure is strictly preferred to child work and it is unclear how this preference affects the household's aggregate utility.

[14] This axiom obtains its name from that fact that, from the household's perspective, child leisure is a luxury good, more of which is consumed as income rises. An early proponent of this inverse relationship, Thomas Malthus noted that the prevalence of child labour in the late 18th century was proof that families were unable to meet their most basic needs (see Edmonds, 2007).

Subsequent replications of this observation spurred numerous attempts at solving the 'wealth paradox' that had become apparent in child labour theory. Bhalotra and Heady (2003) attribute their findings to imperfections in the labour and credit markets as well as household size: If labour markets are imperfect, child labour is increasing in farm size and decreasing in household size, while access to credit spreads the effects out over time (viz., consumption smoothing). Others attempt to resolve the paradox by altering the original luxury axiom. Basu et al. (2010), for instance, propose that the relationship between land wealth and child labour is not monotone - positive or negative - but follows an inverted U-shape. Therefore, child labour will eventually decrease as households become wealthier. Initially, however, an increase in land wealth increases both income and the marginal benefit from child labour. It is only after a structural threshold, beyond which child labour's marginal cost outweighs its benefits, that the relationship reverses direction and child labour decreases for good. This threshold could, for instance, be the income at which the household can afford to contract external labour. [15]

Dwibedi and Marjit (2017) propose another version of the luxury axiom by which child labour decreases in *relative* poverty. This allows for child labour to rise even as every household is made wealthier, as long as the relative distance in wealth between them increases. Their observation that pareto-dominance may not fully characterise poverty mirrors an ongoing debate.[16] Absolute measures of poverty are prone to underestimation and run risk to ignore the amplification of human misery that springs from inequality. Relative poverty indicators, on the other hand, are only strictly relevant in conjunction with absolute measures - a millionaire surrounded by billionaires is not 'poor' in the common sense of the word.[17] While hybrid measures, like 'weakly relative poverty' (Ravallion and

[15]Note that this narrative - things need to worsen before they can get better - resembles the well-known tale of growth and inequality described by the Kuznets Curve (Kuznets, 1955, 1963) and that of growth and pollution described by the Environmental Kuznets Curve (EKC). Notwithstanding their popularity, these narratives remain empirically unsubstantiated. See, however, Piketty (2014) for evidence against the Kuznets curve, and Mills and Waite (2009) and Özokcu and Özdemir (2017) for similar results regarding the EKC.

[16]For poverty measurement techniques of both absolute and relative poverty, as well as their distinction, see Sen (1976) and Ravallion (2019).

[17]This is assuming that the currency used is not a highly inflated one (e.g. Euros rather than Venezuelan Bolívars) and that price levels are comparable to those in the real world.

Chen, 2009) exist, I am not aware of attempts to characterise child labour responses to varying degrees of absolute poverty and income inequality in an integrated framework.[18] Contested to this day, the wealth paradox and the luxury axiom continue to inspire this type of research.[19]

As for their second premise, Basu and Van (1998) model child labour as a substitute for adult labour from the firm's perspective - a notion captured in their 'substitution axiom'. The degree of such substitutability has been debated as well. Due to their lack in experience and bodily development, children are commonly thought to be less suited for most jobs in terms of their productive potential. Bar and Basu (2009) model children to be productive (to some degree) only under adult supervision and entirely unproductive otherwise. While it extends the theory beyond the substitution axiom, their model is likely too restrictive. Toddlers aside, children - including those of very young ages - are capable of performing many simple tasks, making them productive labourers in their own right. This considered, the model presented in section 3 allows for a more realistic characterisation of substitution with and without supervision.

As the literature continues to append Basu and Van's model, it also outgrows it. Many of the more recent studies pay less attention to resolving the wealth paradox or characterising substitution between adult and child labour, but explore instead how child labour is affected through other channels. A natural extension is to explicitly model the allocation of children's time between work and education in terms of opportunity cost. Dynamic models, owing much to human capital theory, describe how households weigh the immediate short term benefits of income-generating child labour against children's future earning ability that increases in education (see e.g. Bar and Basu, 2009; Pal and Saha, 2012; Dendir, 2014; Edmonds and Shrestha, 2014; Chakraborty and Chakraborty, 2018). This crucially depends on the current extent of deprivation, on the rate by which parents discount the future, on whether they view their children's future earnings as a

[18] D'Alessandro and Fioroni (2016) show how political support for child labour regulation is shaped by inequality as it affects the welfare of low skilled adults differently than that of highly skilled ones.

[19] For more examples see e.g. Dumas (2007), Del Carpio (2008), Del Carpio and Loayza (2012), Edmonds and Schady (2012), Sarkar and Sarkar (2016), Oryoie et al. (2017), and Noack (2019).

consumption smoothing mechanism for themselves (e.g. during old age), and also on their altruism towards their children.[20]

Another extension is to model the role of markets. Baland and Robinson (2000),Bhalotra and Heady (2003), and Dumas (2007) investigate how imperfections in the credit and (adult-)labour markets could cause households to deploy relatively more or less child labour. Basu et al. (2010) rely, in part, on the absence of functioning labour markets to arrive at their inverted U-shape. Dumas (2013, 2015, 2020) characterises a whole range of scenarios by selectively switching markets on and off one at a time and observing the effect on child labour in her model. To date, the literature largely confirms the moderating effects of labour markets and, less clearly so, the deferring effects of credit markets. Overall, child labour theory has evolved into a framework, capable of analysing child labour in relation to the wider micro-economic context that surrounds it.

Finally, the studies that are closest related to mine focus on the effects of external shocks on such a system. Dumas (2015, 2020) uses rainfall as a shock on household production in agriculture and, thus, indirectly on the households' child labour supply decision. She finds that, in the case of Tanzania, child labour increases in rainfall and that this increase is attenuated if the household has access to a well-functioning labour market. Moreover, her findings indicate that credit markets are less effective in smoothing such rainfall shocks. Manual labour provision can solve the household's problem contemporaneously (harvesting or sowing before the crops rot or the ground dries up), whereas consumption smoothing by credit only protracts costs into the future as long as the underlying problem remains unsolved. Of course, access to credit is usually quite limited in developing countries and particularly so among the poorest. Furthermore, there is only so much credit a poor farming household can take up, assuming there is a functioning market, before it is worse off than before. Lastly, climate change is neither idiosyncratic nor transient, which makes it virtually impossible to insure against.

Boutin (2014) is the only paper to date which explicitly studies the link between cli-

[20]Knowing that they may well die before the fruits of child education can be reaped, purely self-interested parents may prefer sending their children to work and enjoy additional income presently.

mate change and child labour. Boutin's approach is, however, less direct than that used in Dumas' rain-shock study. She measures climate vulnerability rather than effectuated climate change itself. Her independent variable is an aggregate of two indices that "take into account the multidimensionality of climate change"; one index on biophysical vulnerability defined over climate volatility, variability, landscape typology and soil structure, and another index measuring a community's adaptive capacities, which takes into account diversification strategies, financial capacities, and community-level amenities. One advantage of using such a composite index is that it overcomes potential endogeneity problems:

> Households whose income and assets are most vulnerable to climate damage will benefit more from income diversification generated by child labour than other households. Consequently, they might be more likely to have a child working that can smooth consumption in the event of a severe climate shock. This would also be the case if risk-adverse households are more likely to have working children in order to diversify income sources and are also more likely to invest in self-protection mechanisms (Boutin, 2014, p.5).

Endogeneity of this kind aside, concerns about measurement error as well as the cross-sectional nature of Boutin's data still complicate causal inference. Her climate vulnerability index is certainly a valuable contribution, especially when it comes to designing forward looking adaptation policies. Much of the pertinent policy debate, however, centres around quantifying the impacts of exposures to adverse effects of climate change rather than the human response to an increase in vulnerability per se.[21] Therefore, this paper focuses on the effects of eventuated climate change - more frequent episodes of drought or flooding and persistent shifts in mean temperature and precipitation - on child labour. Although Boutin's metrics are different from the ones deployed here (vulnerability towards climate change versus actual, exogenously apportioned exposure to its negative effects), her findings provide a benchmark against which to compare the present study. Boutin finds that climate vulnerability negatively affects child labour incidence and intensity, while it does not seem to have an impact on household chores. Thus, she concludes that child labour is an adjustment variable to local labour market conditions but not correlated with a given

[21] On the attribution of a single event to climate change, see Hansen et al. (2014).

communities' joint climate resilience (Boutin, 2014).

The identification approach in this paper is much closer related to the rain induced shock used in Dumas (2020); I use multiple weather-component variables to shock the system and relate them back to changes in the climate. To guide the formulation of this second part of my model, I now offer a brief overview of the literature on climate change and its effects on the socio-economic sphere.

2.2 Agriculture and Labour Supply

In the field of Agricultural, Resource and Environmental Economics (ARE) there is a long history of using weather measures as explanatory variables in statistical models of agricultural productivity (e.g. Fisher, 1925). The reason for this is simple: Setting labour, machines, and fertilizer aside, the inputs to agricultural production are biophysical variables like soil nutrients, sunlight, rainfall, temperature, or pests. As such, a change in weather affects them much more immediately than it would affect most inputs in other sectors. But there are also considerable social and economic factors at play; Crop choice, the use of fertilizers or pesticides, capital and machinery used to till and harvest, and long-term planning of plot use rotation are all examples of human decision variables that interact with the aforementioned physical ones. The exact form of these human-nature interactions are subject to economic decision-making and depend on the farmers' preferences as well as on their constraints, environmental and otherwise. Figure 1 schematically depicts such a production process from the farmer's perspective.

Labour supply depends in many ways on all the other factors to fall in place first: No additional harvesters are needed if, for example, a drought wipes out your crops before they are ripe. It is this connection between the physical conditions for agriculture and the human labour inputs to it, which may prove helpful for exploring the more specific characteristics of child labour supply in that sector.

One consequence of the complex nature-human interactions that characterise agricultural production is that the productivity of labour cannot be observed directly by the

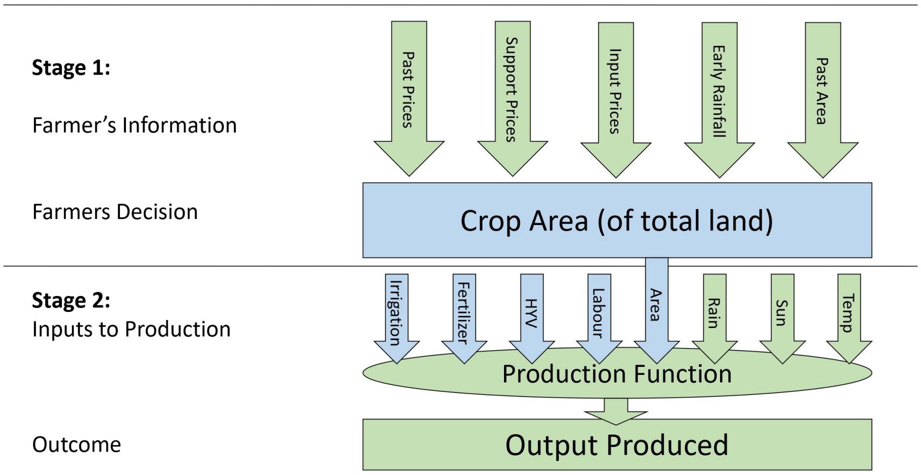

Figure 1: The farmer's problem.

Note: At stage 1, the farmer observes relevant information, the realization of which is exogenous. Based on this, the farmer apportions some land for planting a given crop. In stage 2, inputs enter the production function (HYV = high yield variety). Inputs depicted by blue arrows are choice variables for the farmer, green ones are not. *Source:* adapted from Auffhammer (2014).

executive farmer, even if he were to monitor all workers constantly. Indirect measures of productivity, such as the number of tasks performed per worker, are also unavailable for most of the productive cycle: At harvest, one can judge the amount of produce harvested per worker and, at planting, the quantity of seeds sown or the area of land covered. Between planting and harvesting, however, labour productivity is not straight forward to measure indirectly as growth and crop quality are mostly determined by environmental factors. Since total production at the end of the harvest is a complex function of many worker's individual contributions and of the environment over time, individual workers' inputs cannot be easily disaggregated or compared. Thus an informational asymmetry arises.

One result of this is the inverse relationship between a farm's size and its productivity, which was first noted in the case of India (Sen, 1962) and has since been evidenced across the developing world. The literature shows quite convincingly that - holding inputs constant - small family owned farms are more productive than bigger enterprises. There is disagreement, however, on whether this is due to the lesser extent of moral hazard (e.g.

shirking) among family members vis a vis wage workers[22], or due to the spatial dispersion of workers on bigger farms which drives up monitoring costs (Sen, 1981). Either way, free-riding seems to be less of a problem on family-farms without labour market connections.

On the other hand, labour markets are crucial for insuring against crop failure. Kochar (1999) presents evidence suggesting that the smoothness of household consumption in the presence of farm-specific crop income shocks reflects the ability of households to smooth income directly, by increasing their market hours of work. This is an early pointer to the important role that labour markets play in household consumption smoothing and, consequently, its effects on child labour allocation discussed in Dumas (2015, 2020).

2.3 Economic Effects of Climate Change

Since child labour is not prominently featured as a topic in the ARE, the importance of this literature for the present study lies predominantly in providing a framework that can link climate and weather to socio-economic phenomena *like* child labour.

Indeed, the relatively recent empirical literature on the economic impacts of climate change has turned the spotlight onto quantifying the effect of climate on many different socio-economic outcomes. Table 1 gives a non-exhaustive list of such studies. Most of them report highly nonlinear relationships between climate and the outcomes of interest (e.g. Schlenker and Roberts, 2009; Hsiang et al., 2015), and warm temperatures seem to be a particularly relevant factor for many climate responses (Auffhammer et al., 2013).

[22]Household members have a direct interest in maximising farm output because their consumption is directly dependent on it. Wage workers, on the other hand, can benefit from defecting behaviour as long as output remains high enough so that a decline can credibly be attributed to solely environmental factors and wages continue to be paid.

Table 1: Selected climate impact studies from ARE Economics.

Notes: Studies by subject areas, denoting the type of climate variables used (P=precipitation, T=temperature, various) and the type of response variable for which the study controls. Location type (IC=industrial countries, DC=developing countries, SSA=Sub-Saharan Africa) provided where applicable. Note that climate variable types may indicate the use of more than one metric pertinent to that climate component, e.g. mean, maximum, minimum, etc. *Source:* own compilation.

	Paper	**Climate Variables**	**Response Variable**
Agriculture	Deschênes and Greenstone (2007)	various	yields (IC)
	Mendelsohn (2008)	various	yields (DC)
	Schlenker and Roberts (2009)	various	yields (IC)
	Schlenker and Lobell (2010)	various	yields (SSA)
	Welch et al. (2010)	various	yields (DC)
	Lobell et al. (2011)	various	yields (globally)
	Hertel and Lobell (2014)	various	yields (DC)
Macro/Trade	Barrios et al. (2010)	P	growth (SSA)
	Jones and Olken (2010)	T, P	exports
	Hsiang et al. (2015)	various	aggregate output
	Costinot et al. (2016)	various	trade advantage
	Deryugina and Hsiang (2017)	various	aggregate output
	Dingel et al. (2019)	various	trade inequality
	Burke and Tanutama (2019)	various	aggregate output
	Schlenker and Taylor (2019)	various	market outlook
Migration	Feng et al. (2010)	various	yields, migration
	Marchiori et al. (2012)	various	migration (SSA)
	Cattaneo and Peri (2016)	T	migration
	Missirian and Schlenker (2017)	T	migration
Health	Deschênes (2014)	various	mortality rates
	Isen et al. (2017)	T (in utero)	adult well being
	Obradovich et al. (2017)	T	sleep
	Burke et al. (2018)	T	suicide rates
	Baylis (2020)	T	temperament
Warfare	Hsiang et al. (2011)	various	conflict
	Hsiang et al. (2015)	various	conflict
Energy	Auffhammer and Mansur (2014)	various	electricity demand

While the details differ, most of these papers roughly follow a two step procedure: first weather data is merged with data on the outcome of interest as well as some control variables. From this data set, a function describing the climate effect - called dose-response function or damage function - is estimated. The relevant coefficients are often estimated numerically due to the highly nonlinear nature of climate effects. Once obtained, the dose-response function is used to project future effects of climate change. To this end, climate projections from a global climate model (GCM) are passed to the function. The function's output are then interpreted as the projected future values of the dependent variable.[23]

The related methodological literature, in particular Timmins and Schlenker (2009); Schlenker (2010); Auffhammer et al. (2013); Hansen et al. (2014); Auffhammer (2018) and Hsiang (2016), has developed a range of econometric strategies for estimating dose response functions, forecasting, and drawing climate insights from weather data. I make use of the framework in Hsiang (2016) in building a first bridge between this empirically driven literature from ARE and the aforementioned literature on child labour. Conceptually, rainfall, temperature, and other weather components are modelled to be jointly drawn from an underlying distribution which is commonly called 'climate'.

In order to model climate change and its effects, one must first define what exactly climate is. We never directly observe climate. What people perceive in their immediate environment is weather and it is weather, not climate, that has an immediate effect on their lives. Hermeneutics complicate this distinction further: humans learn from repeated experience, develop foresight, and adapt. As a result, Weather can have direct and indirect effects. Direct effects of rain, for instance, include getting wet or losing harvest due to flooding. Analogous indirect effects are wearing a rain coat next time and installing a drainage system to safeguard crops. Thus, direct and indirect effects of weather are increasingly convoluted over time and space.

This distinction also exists, as immediate versus down-stream effects, in the Environmental Impact Assessment (EIA) literature (see e.g., Noble, 2015). Furthermore, EIA's distinguish between environmental changes and effects. Assuming that there is always some level of change in the ecosystem, environmental effects are then those additional

[23]This approach by itself has been dubbed the "dumb farmer scenario" (Auffhammer and Schlenker, 2014), as it implicitly assumes that farmers continue business as usual despite climate change. Widely used adaptations of this approach adopt additional assumptions to address climate adaptation or even model it explicitly.

changes induced by external shock to the system - the difference in differences. This broad conceptualisation of all environmental effects, transitory or persistent, neatly encompasses climate change.

The notion of human foresight about the weather is crucial as it suggests an implicit characterisation of climate as a probability distribution. While we may not exactly know ex ante what the weather will be at our position in a given future moment, we might have accumulated prior expectations about the 'usual' extent to which precipitation, temperature, wind gusts, and other weather components tend to vary, about their typical transitory pace, and even about the approximate probabilities attached to each possible state conditional on the eventuated past and on the contemporaneous variance observed in other related weather components.

In developing such expectations, humans display an approximate understanding of the bio-physical processes underlying the weather as they learn to appreciate the observable interdependence structure across weather components induced by these processes. Continuous observation of the weather is then equivalent to drawing independent random draws from an underlying distribution. As long as this distribution remains unaltered, the accuracy of one's expectations increases with the number of draws. Precipitation, for instance, differs by temperature and we intuitively expect snow when the temperature falls below zero degrees centigrade, but rain above that threshold. As long seasonal variation of temperature stays constant, this enables long-term planning of all kinds of economic activity in humans, as well as survival strategies in animals (e.g., hybernation) and plants (e.g., shadding foliage) more broadly. Equivalent long-term strategies occur everywhere on planet earth, always specifically geared towards the local climate.

Recent evidence from the United States shows that humans are surprisingly fast in correcting their expectations to account for climate change. The subjective baseline against which temperature is evaluated appears to be dominated by recent experience. In consequence, "temperatures initially considered remarkable rapidly become unremarkable with repeated exposure over a roughly 5 year timescale" (Moore et al., 2019). This rapid expectation adjustment relative to the pace of anthropogenic climate change has large implications for the notability of temperature anomalies as climate change progresses.[24] It also means that the two-fold effects of the static climate distribution - on effectuated weather and on people's expectations about it respectively - may carry over to the non-static setting with climatic change quite seamlessly. In the empirical application, presented in section 4, this persistence of causal links across time is formalised and serves the identification of treatment effects. Before, I present an economic model that is capable of generating hypotheses about the effect of climate change on child labour.

3 Model

The model presented in this section draws from Jessoe et al. (2018). Their model, in turn, is a version of the standard agricultural household model (Singgh et al., 1986) with weather as an additional production factor. In this class of models, the household solves the production and consumption sides simultaneously, resembling their dual role as producers and consumers.

Two additional extensions are necessary in order to adapt this framework to the analysis of child labour. First, the household's aggregate utility function, which is left unspecified in Jessoe et al. (2018), should exhibit child labour aversion in line with the luxury axiom (Basu and Van, 1998). Secondly, the effective labour input L must be disaggregated into child and adult labour. Furthermore, the functional form of adult-equivalent child labour units needs to be specified in order to accommodate complementarity and appropriately scale total time input according to the differences in productive capacity between child and adult labour time units. Following some preliminaries, I implement these extensions and solve the household's utility maximization problem.

Preliminaries: The ILO defines child labour as

> work that is mentally, physically, socially or morally dangerous and harmful to children; and that interferes with the children's schooling by depriving them of the

[24]Notably, this attenuating presence-bias surrounding human perception of extreme weather may inhibit societal pressure for climate change mitigation efforts.

> opportunity to attend school, either by obliging them to leave school prematurely, or by requiring them to attempt to combine school attendance with excessively long and heavy work.

Because the various components of this definition are often hard to establish in practice, age is commonly used as a proxy by which to distinguish benign work from child labour. The ILO's Convention No. 138 stipulates the relevant ages that different countries use to define child labour. In applied work, therefore, the age threshold needs to be adjusted to the relevant country context, with the upper limit at eighteen years in any case. In formulating a theoretical model, such an adjustable age threshold can be implemented on any household's age-ordering. Consider an agricultural household $\mathcal{I} = \{1, 2, ..., I\}$ whose $I > 0$ members are ordered from youngest to oldest. Let a_i be the age of household member $i \in \mathcal{I}$. Moreover, let $\underline{a}$ be the legal age at which an individual is no longer considered a child. Accordingly, i is a child if $a_i < \underline{a}$ and an adult if $a_i \geq \underline{a}$.

Every member of the household is endowed with time, normalized at 1, and spends a fraction l_i of it working on the household's farm. The remainder of time $(1 - l_i)$ is non-work.[25] Note that aggregate time endowment up to a given individual is equal to the number of individuals it has been aggregated over. For example, the aggregate time endowment of adults in $\mathcal{I}$ is $(I - \hat{\imath})$, where $\hat{\imath}$ indicates the oldest child in the household. Note that lower case letters denote individual information and upper case letters aggregate information across individuals. Subscripts in lower case denote indices whereas upper case subscripts either refer to the last element of an index (as in $I \in \mathcal{I}$) or attach labels to aggregate variables; l_i is household member i's time share spent working, whereas $L_C = \sum_{i=1}^{\hat{\imath}}$ and $L_A = \sum_{i=\hat{\imath}+1}^{I} l_i$ denote the aggregate labour supply of children and adults respectively.

Household preferences: Household $\mathcal{I}$ derives utility from the consumption of non-agricultural goods and services X_1, children's leisure X_2, adult's leisure X_3, and agricultural goods X_4. Additionally, the household's decision makers are averse to child labour, as long subsistence consumption levels can be reached without it. The following Stone-Geary type

[25]For adults, this is equivalent to leisure. For children, non-work may involve going to school as well as leisure.

utility function with an additional child-leisure factor captures this trade-off (cf. Basu and Van, 1998):

$$U(\mathbf{X}) = \begin{cases} (\hat{\imath} - L_C) & \prod_{n=1}^{4}(X_n - S_n)^{\alpha_n}, \text{ if } X_n \geq S_n \forall n \\ & \prod_{n=1}^{4}(X_n - S_n)^{\alpha_n}, \text{ if } X_n < S_n \text{ for any } n \end{cases}, \tag{1}$$

where, $\forall n \in \{1,2,3,4\}, S_n$ is the subsistence level of consumption good X_n, $\alpha_n \geq 0$, and $\sum_n \alpha_n = 1$. The term to the left of the product sign in the first case captures children's aggregate non-work. Its absence in the second line indicates that the household's preferential treatment of children seizes when consumption falls below subsistence in any of the four categories.

Labour equivalence: Children tend to be less productive than adults. In agriculture, this stems from differences in physical strength, skill-refining experience, ability to manage equipment, and other productive traits - all of which favour adults.[26] It is common practice to simply attach an adult-equivalence factor $v \in [0,1]$ to child labour, making it an imperfect substitute for adult labour (Basu and Van, 1998; Baland and Robinson, 2000; Bhalotra and Heady, 2003; Basu et al., 2010; Dwibedi and Marjit, 2017; Dumas, 2020).[27]

Bar and Basu (2009) extend this substitution axiom (Basu and Van, 1998), contending that child labour must be supervised, using proportional amounts of adult labour, in order to be productive. In their model, children are employed when matched with an appropriate amount of adult supervision and left idle otherwise; child and adult labour are substitutes within a bound beyond which they become complements. Toddlers aside, their underlying assumption might be too restrictive; Once instructed, even young children are

[26]The opposite is true when a productive activity requires specific characteristics that are more readily available in children. One particularly cruel example is mining in confined underground spaces, where children's small size allows for easier access and faster extraction of precious ores while minimising drilling costs (see e.g. O'driscoll, 2017).

[27]Similar household equivalence scales are commonly used in estimating household consumption systems, with children (the elderly) consuming a fraction (multiple) of adult consumption. For reference, see Pollak and Wales (1979), Lewbel (1989), Blundell et al. (1994), Lewbel (1997), or Deaton (1999). While they are increasingly considered to be overly simplistic, equivalence scales are used in more involved methods (see e.g. Dunbar et al. (2013).

able to replicate a multitude of simple tasks without constant monitoring. Rather than establishing child productivity, therefore, adult supervision can be thought to extend a low innate productive capacity. As a result, the household may make use of a given child's labour even when there is not sufficient adult time left to supervise it.

To consider this formally, assume that child labour is necessarily less productive than adult labour by a factor $v(u)$, which specifies the adult-equivalence of child labour if a fraction $u \in (0,1)$ of adult labour is used to supervise the fraction $s \in (0,1)$ of child labour. Supervision generally increases children's productivity, such that

$$0 < \underline{v} \leq v_0 = v(u=0) \leq v(0<u<1) \leq v(u=1) \leq \overline{v} \leq 1 \quad \forall u \in (0,1],$$

where $\underline{v}$ and $\overline{v}$ are the absolute boundaries of children's productive potential. I call s the supervision rate, u the intensity of supervision, $v(u)$ the technology of skill enhancement, and v_0 the adult-equivalence factor of unsupervised child labour (or "raw skill"). In absence of supervision (viz., $s = 0$), the initial adult-equivalent of aggregate child labour input is $v_0 L_C$ and the household's total labour input in this case is $L_{\mathcal{I}} = L_A + v_0 L_C$.

When supervision occurs, the technology of skill enhancement $v(u)$ exhibits monotonicity and decreasing returns to scale from supervision, meaning that

$$\frac{\partial v(u)}{\partial u} > 0, \quad \text{and} \quad \frac{\partial^2 v(u)}{\partial u^2} < 0.$$

Moreover, it must hold that $v(u) > u \quad \forall u \in (0,1)$, since otherwise it would not be worthwhile to invest in supervision. Any monotonically increasing and concave function can be used to represent $v(u)$, provided it meets these few requirements. Figure 2 illustrates the shape of $v(u)$ by the example of the function $v(u) = v_0 + (\overline{v} - v_0)u^{\frac{1}{3}}$, using four different values of v_0.[28]

The adult-labour equivalents of any given combinations of adult and child labour, considering the complementary of supervision in addition to the substitution between L_a

[28]Note that $\overline{v}$ is unambiguously defined as follows from the definition of v and u: $v(u=1) \leq \overline{v} \leq 1$ and $v(u) \geq u \quad \forall u \in (0,1) \iff v(u=1) = \overline{v} = 1$.

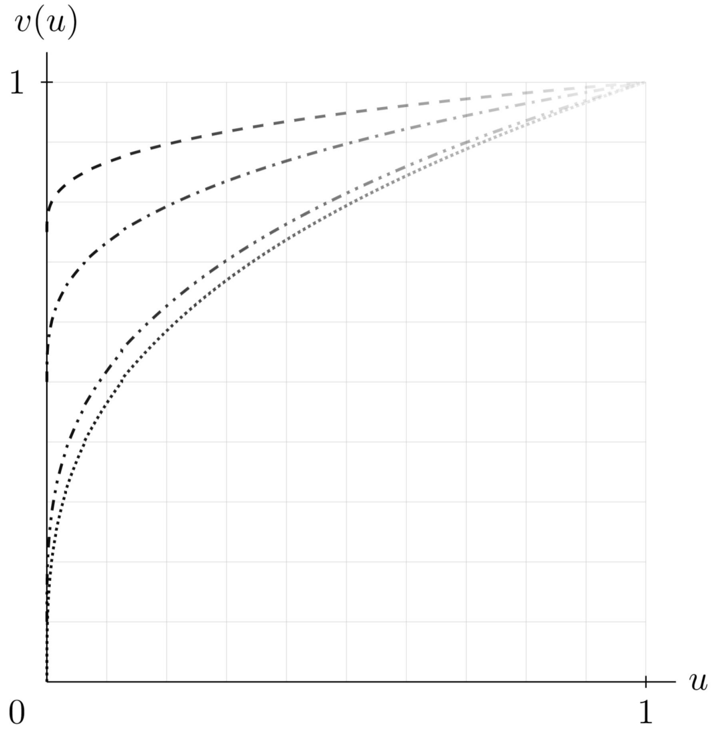

Figure 2: The technology of skill enhancement.

Note: The figure graphs four versions of the function $v(u) = v_0 + (\overline{v} - v_0)u^{\frac{1}{3}}$ for different values of raw skill v_0. The dotted curve corresponds to $v_0 = 0$ and the curves above it to $v_0 = 0.1$, to $v_0 = 0.5$, and to $v_0 = 0.75$ respectively. *Source:* author's own compilation.

and L_c, can be captured by the household's effective labour supply:

$$L_{\mathcal{I}} = \begin{cases} L_A - suL_C + sv(u)L_C + (1-s)v_0 L_C & \text{if} \quad suL_C < L_A \\ v(u)\frac{L_A}{u} + v_0\left(L_c - \frac{L_A}{u}\right) & \text{if} \quad suL_C = L_A \end{cases}. \tag{2}$$

This specification allows for the household decision maker to choose flexibly not only the levels of adult and child labour supply, but also the fraction of children to work with and without supervision, as well as the intensity of such supervision; all this in view of optimising the household's welfare. Setting $v_0 = 0$, $s = 1$, $u < 1$ and $v(u) = 1 \quad \forall u$, equation 2 simplifies to the labour supply function in Bar and Basu (2009). Figure 3 plots combinations of child and adult labour, using the same values for v_0 as in figure 2. The dotted curve on top corresponds to the Bar and Basu perspective that unsupervised child labour must be entirely unproductive (i.e. $v_0 = 0$).[29] Note that along each of these piece-wise linear functions, the effective labour input L stays the same, indicating that, holding other inputs constant, they are isoquants in the farm production problem to which I turn next

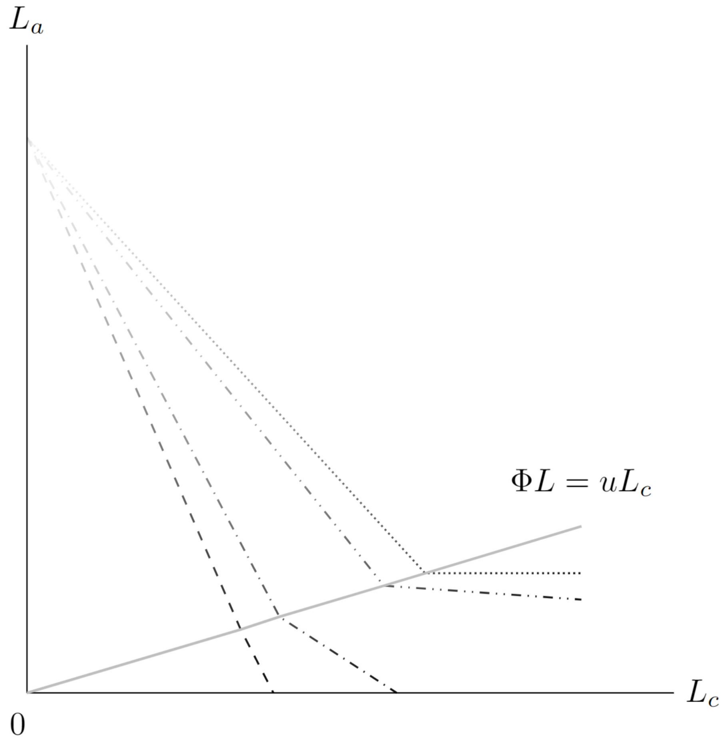

Figure 3: Effective labor isoquants given child- and adult labor units.

Note: The dotted isoquant corresponds to $v_0 = 0$, whereas the isoquants to its left correspond to $v_0 = 0.1$, to $v_0 = 0.5$, and to $v_0 = 0.75$ respectively. The upward sloping line in gray, which connects the isoquant kinks, is defined by its slope, the intensity of supervision u. *Source:* author's own compilations.

Agricultural production: Agricultural products are produced using labour L and quasi-fixed land and capital K. The quantity produced is given by $Q = f(L, \theta, K)$, where $\theta \in \mathbb{R}_+$ is a weather-dependent productivity factor and $f(\cdot)$ is a continuous and twice differentiable production function, for which the following four inequalities hold:

$$\frac{\partial f}{\partial L} > 0 \quad \frac{\partial f}{\partial \theta} > 0 \quad \frac{\partial^2 f}{\partial L^2} < 0 \quad \frac{\partial^2 f}{\partial L \partial \theta} > 0.$$

[29] For all functions graphed in figure 3, it is assumed that $u = 0.1$ and $s = 1$.

Household problem: Household $\mathcal{I}$ is a price-taker in all markets and maximises utility in every period subject to a full income constraint Y, which includes agricultural profits and the value of the household's time endowment I. Formally,

$$\max_{L_A, L_C, X_1, X_2, X_3, X_4} U(\mathbf{X}) \tag{3}$$

$$s.t. \quad p_1 X_1 + p_2 X_2 + p_3 X_3 + p_4 X_4 = Y = p_3 f(L, \theta, K) - p_2 L + p_2 I \tag{4}$$

where p_1, p_2, p_3 and p_4 are the prices for non-agricultural products and services, child labour, adult labour, and agricultural products. Plugging equations (1) and (2) into (3) and (4) above, and solving the production side of this model, it can be shown that

3.1 Hypotheses

4 Empirical application

4.1 Econometric strategy

4.2 Data

5 Findings

6 Conclusion

References

Auffhammer, M. (2014). Economic Impacts of Climate Change on Agriculture. In *Feeding 9 Billion: A Path to Sustainable Agriculture (Day 2, Session 1, iSEE Congress)*.

Auffhammer, M. (2018). Quantifying Economic Damages from Climate Change. *Journal of Economic Perspectives*, 32(4):33–52.

Auffhammer, M., Hsiang, S. M., Schlenker, W., and Sobel, A. (2013). Using Weather Data and Climate Model Output in Economic Analyses of Climate Change. *Review of Environmental Economics and Policy*, 7(2):181–198.

Auffhammer, M. and Mansur, E. T. (2014). Measuring climatic impacts on energy consumption: A review of the empirical literature. *Energy Economics*, 46:522–530.

Auffhammer, M. and Schlenker, W. (2014). Empirical studies on agricultural impacts and adaptation. *Energy Economics*, 46:555–561.

Baland, J.-M. and Robinson, J. A. (2000). Is Child Labor Inefficient? *Journal of Political Economy*, 108(4).

Bar, T. and Basu, K. (2009). Children, Education, Labor, and Land: In the Long Run and Short Run. *Journal of the European Economic Association*, 7(2-3):487–497.

Barrios, S., Bertinelli, L., and Strobl, E. (2010). Trends in Rainfall and Economic Growth in Africal: A neglected cause of the African growth tragedy. *The Review of Economics and Statistics*, 92(2):350–366.

Basu, K., Das, S., and Dutta, B. (2010). Child labor and household wealth: Theory and empirical evidence of an inverted-U. *Journal of Development Economics*, 91:8–14.

Basu, K. and Van, P. H. (1998). The Economics of Child Labor. *The American Economic Review*, 88(3):412–427.

Baylis, P. (2020). Temperature and temperament: Evidence from Twitter. *Journal of Public Economics*, 184:104161.

Becker, G. (1964). *Human Capital: A Theoretical and Empirical Analysis, with Special Reference to Education*. Harvard University Press, Cambridge, MA.

Bhalotra, S. (2002). Parent Altruism.

Bhalotra, S. and Heady, C. (2000). Child Farm Labour: Theory and Evidence.

Bhalotra, S. and Heady, C. (2003). Child Farm Labor: The Wealth Paradox. *Source: The World Bank Economic Review*, 17(2):197–227.

Blundell, R., Preston, I., and Walker, I., editors (1994). *The measurement of household welfare*. Cambridge University Press, Cambridge.

Boeckx, P., Bauters, M., and Dewettinck, K. (2020). Poverty and climate change challenges for sustainable intensification of cocoa systems.

Boutin, D. (2014). Climate Vulnerability, Communities' Resilience and Child Labour.

Burke, M., González, F., Baylis, P., Heft-Neal, S., Baysan, C., Basu, S., and Hsiang, S. M. (2018). Higher temperatures increase suicide rates in the United States and Mexico. *Nature Climate Change*, 8:723–729.

Burke, M. and Tanutama, V. (2019). Climatic Constraints on Aggregate Economic Output. Technical report, National Bureau of Economic Research (w25779), Cambridge, MA.

Cattaneo, C. and Peri, G. (2016). The migration response to increasing temperatures. *Journal of Development Economics*, 122:127–146.

Chakraborty, K. and Chakraborty, B. (2018). Low level equilibrium trap, unemployment, efficiency of education system, child labour and human capital formation. *Journal of Economics/ Zeitschrift fur Nationalokonomie*, 125(1):69–95.

Costinot, A., Donaldson, D., and Smith, C. (2016). Evolving Comparative Advantage and the Impact of Climate Change in Agricultural Markets: Evidence from 1.7 Million Fields around the World. *Journal of Political Economy*, 124(1):205–248.

Craparo, A. C., Van Asten, P. J., Läderach, P., Jassogne, L. T., and Grab, S. W. (2015). Coffea arabica yields decline in Tanzania due to climate change: Global implications. *Agricultural and Forest Meteorology*, 207:1–10.

D'Alessandro, S. and Fioroni, T. (2016). Child labour and inequality. *Journal of Economic Inequality*, 14(1):63–79.

DaMatta, F. M., Rahn, E., Läderach, P., Ghini, R., and Ramalho, J. C. (2019). Why could the coffee crop endure climate change and global warming to a greater extent than previously estimated? *Climatic Change*, 152(1):167–178.

Deaton, A. (1999). *The analysis of surveys, a microeconomic apporach to development policy.* John Hopkins University Press, Baltimore.

Del Carpio, X. V. (2008). Does Child Labor Always Decrease With Income? An Evaluation In The Context Of A Development Program In Nicaragua.

Del Carpio, X. V. and Loayza, N. V. (2012). The impact of wealth on the amount and quality of child labor.

Dendir, S. (2014). Children's cognitive ability, schooling and work: Evidence from Ethiopia. *International Journal of Educational Development*, 38:22–36.

Deryugina, T. and Hsiang, S. M. (2017). The Marginal Product of Climate. Technical report, National Bureau of Investigation (w24072).

Deschênes, O. (2014). Temperature, human health, and adaptation: A review of the empirical literature. *Energy Economics*, 46:606–619.

Deschênes, O. and Greenstone, M. (2007). The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather. *American Economic Review*, 97(1):354–35.

Dingel, J. I., Meng, K. C., and Hsiang, S. M. (2019). Spatial Correlation, Trade, and Inequality: Evidence from the Global Climate. Technical report, National Bureau of Economic Research (w25447), Cambridge, MA.

Dumas, C. (2007). Why do parents make their children work? A test of the poverty hypothesis in rural areas of Burkina Faso. *Oxford Economic Papers*, 59:301.

Dumas, C. (2013). Market Imperfections and Child Labor. *World Development*, 42:127–142.

Dumas, C. (2015). Shocks and child labor: the role of markets.

Dumas, C. (2020). Productivity Shocks and Child Labor: The Role of Credit and Agricultural Labor Markets. *Economic Development and Cultural Change*, 68(3):763–812.

Dunbar, G. R., Lewbel, A., and Pendakur, K. (2013). Children's Resources in Collective Households: Identification, Estimation, and an Application to Child Poverty in Malawi. *The American Economic Review*, 103(1):438–471.

Dwibedi, J. K. and Marjit, S. (2017). Relative Affluence and Child Labor - Explaining a Paradox. *Review of Development Economics*, 21(4):1178–1190.

Edmonds, E. V. (2007). Child Labor.

Edmonds, E. V. and Schady, N. (2012). Poverty Alleviation and Child Labor. *American Economic Journal: Economic Policy*, 4(4):100–124.

Edmonds, E. V. and Shrestha, M. (2014). You get what you pay for: Schooling incentives and child labor . *Journal of Development Economics*, 111:196–211.

Feng, S., Krueger, A. B., and Oppenheimer, M. (2010). Linkages among climate change, crop yields and Mexico-US cross-border migration. *Proceedings of the National Academy of Sciences*, 107(32):14257–14262.

Fisher, R. A. (1925). The influence of rainfall on the yield of wheat at Rothamsted. *Philosophical Transactions of the Royal Society of London. Series B, Containing Papers of a Biological Character*, 213(402-410):89–142.

Hansen, G., Auffhammer, M., and Solow, A. R. (2014). On the Attribution of a Single Event on Climate Change. *Jornal of Climate*, 27(22):8297–8301.

Hertel, T. W. and Lobell, D. B. (2014). Agricultural adaptation to climate change in rich and poor countries: Current modeling practice and potential for empirical contributions. *Energy Economics*, 46:562–575.

Hsiang, S. M. (2016). Climate Econometrics. *Annual Review of Resource Economics*, 8(1):43–75.

Hsiang, S. M., Burke, M., and Miguel, E. (2015). Climate and Conflict. *Annual Review of Economics*, 7(1):577–617.

Hsiang, S. M., Meng, K. C., and Cane, M. A. (2011). Civil conflicts are associated with the global climate. *Nature*, 476(7361):438–441.

Ibrahim, A., Abdalla, S. M., Jafer, M., Abdelgadir, J., and De Vries, N. (2018). Child labor and health: a systematic literature review of the impacts of child labor on child's health in low-and middle-income countries. *Journal of Public Health*, 41(1):18–26.

ILO (2017). Global Estimates of Child Labour: Results and trends 2012-2016. Technical report, International Labour Office, Geneva.

IMF (2020). Regional Economic Outlook: Sub-Saharan Africa. Technical report, International Monetary Fund, Washington, DC.

Isen, A., Rossin-Slater, M., and Walker, R. (2017). Relationship between season of birth, temperature exposure, and later life wellbeing. *Proceedings of the National Academy of Sciences*, 114(51):13447–13452.

Jessoe, K., Manning, D. T., and Taylor, J. E. (2018). Climate Change and Labour Allocation in Rural Mexico: Evidence from Annual Fluctuations in Weather. *The Economic Journal*, 128(608):230–261.

Jones, B. F. and Olken, B. A. (2010). Climate Shocks and Exports. *American Economic Review: Papers and Proceedings*, 100:454–459.

Kochar, A. (1999). Smoothing consumption by smoothing income: Hours-of-work responses to idiosyncratic agricultural shocks in Rural India. *Review of Economics and Statistics*, 81(1):50–61.

Kuznets, S. (1955). Economic Growth and Income Inequality. *The American Economic Review*, 45(1):1–28.

Kuznets, S. (1963). Quantitative Aspects of the Economic Growth of Nations: VIII. Distributions of Income by Size. *Economic Development and Cultural Change*, 11(2):1–80.

Lewbel, A. (1989). Household equivalence scales and welfare comparisons. *Journal of Public economics*, 39:377–391.

Lewbel, A. (1997). Comsumer demand systems and household equivalence scales. In Pesaran, H. and Schmidt, P., editors, *Handbook of applied econometrics (Microeconomics, Vol. II)*. Oxford, blackwell edition.

Lobell, D. B., Schlenker, W., and Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. *Science*, 333(6042):616–620.

Marchiori, L., Maystadt, J.-F. O., and Schumacher, I. (2012). The impact of weather anomalies on migration in sub-Saharan Africa. *Journal of Environmental Economics and Management*, 63:355–374.

Marx, K. and Engels, F. (1848). *The Communist Manifesto*. New York, appelton c edition.

Mendelsohn, R. (2008). The Impact of Climate Change on Agriculture in Developing Countries. *Journal of Natural Resources Policy Research*, 1(1):5–19.

Mills, J. H. and Waite, T. A. (2009). Economic prosperity, biodiversity conservation, and the environmental Kuznets curve. *Ecological Economics*, 68(7):2087–2095.

Mincer, J. (1958). Investment in Human Capital and Personal Income Distribution. *Journal of Political Economy*, 66(4):281–302.

Missirian, A. and Schlenker, W. (2017). Asylum applications respond to temperature fluctuations. *Science*, 358(6370):1610–1614.

Moore, F. C., Obradovich, N., Lehner, F., and Baylis, P. (2019). Rapidly declining remarkability of temperature anomalies may obscure public perception of climate change. *Proceedings of the National Academy of Sciences of the United States of America*, 116(11):4905–4910.

Munasinghe, L., Jun, T., and Rind, D. H. (2012). Climate change: A new metric to measure changes in the frequency of extreme temperatures using record data. *Climatic Change*, 113(3-4):1001–1024.

Noack, F. (2019). Resource Abundance and Education. *Economic Development and Cultural Change*, 68(2):699–727.

Noble, B. F. (2015). *Environmental Impact Assessment: A Guide to Priniples and Practice.* Oxford University Press, Canada, Don Mills, Ontario, 3 edition.

Obradovich, N., Migliorini, R., Mednick, S. C., and Fowler, J. H. (2017). Nighttime temperature and human sleep loss in a changing climate. *Science Advances*, 3(5):1–6.

O'driscoll, D. (2017). Overview of child labour in the artisanal and small-scale mining sector in Asia and Africa. Technical report, Institute of Development Studies, Brighton, UK.

Oryoie, A. R., Alwang, J., and Tideman, N. (2017). Child Labor and Household Land Holding: Theory and Empirical Evidence from Zimbabwe. *World Development*, 100:45–58.

Özokcu, S. and Özdemir, Ö. (2017). Economic growth, energy, and environmental Kuznets curve.

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., Church, J. A., Clarke, L., Dahe, Q., Dasgupta, P., Dubash, N. K., Edenhofer, O., Elgizouli, I., Field, C. B., Forster, P., Friedlingstein, P., Fuglestvedt, J., Gomez-Echeverri, L., Hallegatte, S., Hegerl, G., Howden, M., Jiang, K., Jimenez Cisneros, B., Kattsov, V., Lee, H., Mach, K. J., Marotzke, J., Mastrandrea, M. D., Meyer, L., Minx, J., Mulugetta, Y., O'Brien, K., Oppenheimer, M., Pereira, J. J., Pichs-Madruga, R., Plattner, G.-K., Pörtner, H.-O., Power, S. B., Preston, B., Ravindranath, N., Reisinger, A., Riahi, K., Rusticucci, M., Scholes, R., Seyboth, K., Sokona, Y., Stavins, R., Stocker, T. F., Tschakert, P., van Vuuren, D., and van Ypersele, J.-P. (2015). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Technical report, International Panel on Climate Change, Geneva.

Pal, S. and Saha, B. (2012). Self-Employment and Child Labour: Theory and Evidence.

Piketty, T. (2014). *Capital in the Twenty-First Century*. Belknap Harvard, Cambridge, MA.

Pollak, R. A. and Wales, T. J. (1979). Equity; the individual versus the family: Welfare comparisons and equivalence scales. *American Economic Review*, 69:216–221.

Posso, A., editor (2020). *Child Labor in the Developing World: Theory, Practice, and Policy.* Springer Singapore, Singapore.

Ravallion, M. (2019). On Measuring Global Poverty.

Ravallion, M. and Chen, S. (2009). Weakly Relative Poverty.

Ritchie, H. and Roser, M. (2017). CO2 and Greenhouse Gas Emissions.

Rosenzweig, M. R. and Evenson, R. (1977). Fertility, Schooling, and the Economic Contribution of Children of Rural India: An Econometric Analysis. *Econometrica*, 45(5):1065.

Sarkar, J. and Sarkar, D. (2016). Why Does Child Labour Persist With Declining Poverty? *Economic Inquiry*, 54(1):139–158.

Schlenker, W. (2010). Crop Responses to Climate and Weather: Cross-Section and Panel Models. In Lobell, D. and Burke, M., editors, *Advances in Global Change Research*, volume 37, chapter 6, pages 99–108. Springer, Dordrecht.

Schlenker, W. and Lobell, D. B. (2010). Robust negative impacts of climate change on African agriculture. *Environmental Research Letters*, 5:1–8.

Schlenker, W. and Roberts, M. J. (2009). Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. *Proceedings of the National Academy of Sciences*, 15(37):15594–15598.

Schlenker, W. and Taylor, C. A. (2019). Market Expectations About Climate Change. Technical report, National Bureau of Economic Research (w25554), Cambridge, MA.

Schultz, T. W. (1961). Investment in Human Capital. *American Economic Review*, 51(1):1–17.

Sen, A. (1981). Market failure and control of labour power: towards an explanation of 'structure' and change in Indian agriculture. Part 1. *Cambridge Journal of Economics*, 5(3):201–228.

Sen, A. K. (1962). An Aspect of Indian Agriculture. *The Economic Weekly*, (Annual Number 14):243–243.

Sen, A. K. (1976). Poverty: An Ordinal Approach to Measurement. *Econometrica*, 44(2):219.

Singgh, I., Squire, L., and Strauss, J., editors (1986). *Agricultural Household Models: Extensions, Applications, and Policy.* Johns Hopkins University Press, Baltimore and London.

Timmins, C. and Schlenker, W. (2009). Reduced-Form Versus Structural Modeling in Environmental and Resource Economics. *Annual Review of Resource Economics*, 1(1):351–380.

Tol, R. S. J. (2009). The Economic Effects of Climate Change. *Journal of Economic Perspectives*, 23(2):29–51.

UNICEF (2020). Child labour.

Welch, J. R., Vincent, J. R., Auffhammer, M., Moya, P. F., Dobermann, A., and Dawe, D. (2010). Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivities to minimum and maximum temperatures. *Proceedings of the National Academy of Sciences*, 107(33):14562–14567.