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Quantifying India's Climate Vulnerability[§]

ABSTRACT This paper asks about the climate damages that Indian policymakers can expect. What is the likely magnitude of climate damages, and how sensitive are they to the level of warming? How much worse would climate damages be for Indians under, say, 5° of warming rather than 3°? Understanding the magnitude of climate damages and how rapidly they increase as temperature change increases is critical for finding the right climate mitigation policy. This paper provides projections of India's climate vulnerability on the basis of new microeconomic and macroeconomic evidence. The authors' quantifications show that India is highly vulnerable to climate damage. Their baseline macroeconomic approach suggests that climate change peaking at 5°C, rather than 3°C, would be as detrimental to Indian well-being as a reduction in GDP by about 18 percent for each of the years from 2020 to 2040. Such an equivalent threat to near-term economic outcomes would be an overriding policy priority if political leaders anticipated it. The authors' microeconomic results suggest that this may be an underestimate, because it ignores humidity. Emerging evidence suggests that humans are especially vulnerable to exposure to high temperatures in contexts of high humidity; humidity is a previously underappreciated and unquantified reason way in which India may be more climate-vulnerable even than some hotter developing and middle-income countries.

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JEL Classification: *Q51, Q58, O11, H23, E10*

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1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) predicts an overall increase in the earth's temperature over the next century due to climate change caused by human greenhouse gas (GHG) emissions, calling it "virtually certain" that there will be more frequent hot temperature extremes and less frequent cold temperature extremes experienced over most land areas (Solomon et al. 2007). A large body of literature from the IPCC and other researchers has estimated or projected economic, health, and other costs of climate change, finding that the net effect on humans will be negative on balance and potentially very large (Field et al. 2014).

Much of this literature focuses on developed countries. Less is known about the adverse effects of exposure to higher future temperatures on health and economic activity in developing countries and emerging economies. As leading economists recently argued in *Science*, the focus in the prior literature on rich countries is "problematic, both because developing countries currently represent the majority of the world's population and GHG emissions and because the nature of impacts and context for policy choice could differ greatly relative to developed regions" (Burke et al. 2016). Exposure to extreme temperatures is often greater in developing nations, which are disproportionately located in the hotter tropics. Harms conditional on exposure could also be greater: the poor may be less resilient to weather's impacts due to worse overall health. And poor populations may be less able to adapt by reducing exposure to extreme heat and humidity, such as via climate-controlled housing and indoor work.

This paper asks about the climate damages that Indian policymakers can expect: what is the likely magnitude of climate damages, and how sensitive are they to the level of warming? In other words, how much worse would climate damages be for Indians under, say, 5° of warming rather than 3°? Understanding the magnitude of climate damages and how rapidly they increase as temperature change increases is critical for finding the right climate mitigation policy. Reducing emissions has costs, in part because emissions are a by-product of productive economic activity, and in part because cleaner fuel choices can be more expensive than carbon-emitting fuel choices. These costs are especially salient for a developing country such as India, where many households still lack reliable electricity, and where foregone economic growth implies an important loss of well-being for all Indians.

Public economics has a straightforward theoretical answer to externality problems such as climate change, where one decision-maker's action causes external harm to other people. Policy should be chosen so that the marginal social costs of reducing pollution equal the marginal social costs of the harm that is being averted. Still, applying this simple theory is difficult. One difficulty lies in even knowing the quantitative extent of the harm. Because climate change will impact many people—rich and poor; urban and rural; men and women; voting age citizens and their young children and future descendants—understanding the total sum of the harm requires comparing unalike consequences for unalike people (Dennig et al. 2015; Edenhofer et al. 2014).

Another well-known difficulty is the politics of collective action: the globally optimal policy package, if it could be enforced for the whole world, may importantly differ from what is in the interest of one country's population, especially the people alive at one time. Under the 2015 Paris Agreement, global mitigation policy will be made through countries' own bottom-up pledges (Budolfson et al. 2019; UNFCCC 2015). To know what to pledge, Indian policymakers need to know the stakes for India. Therefore, our research speaks to the question of what it would be rational for an Indian policymaker to choose in the self-interest of the full Indian population, present and future. As we will detail, when we tally the social costs of climate change, we consider only costs to the population of India.

In short, we find that the cost of climate damages for India is likely to be very large. Although India's climate vulnerability has been widely discussed in the prior literature, quantification is necessary for domestic analysis and policymaking. Moreover, emerging evidence suggests that Indians may bear an even greater share of global climate damages than has been previously understood. For example, because of the combination of heat and humidity of the Indian monsoon months, and because human bodies are more stressed by thermoregulation in humid air than in dry air, India may face a much larger early-life mortality burden from climate change than sub-Saharan Africa (Geruso and Spears 2018). Among the many tragedies of climate change is the fact that India and other developing countries have not been responsible for much of the world's carbon emissions to date, but Indians nevertheless stand to lose much from climate change. Our quantification of these losses emphasizes the depth of the policy challenge: what is India's best, rational response to this climate injustice?

This paper reviews and integrates microeconomic and macroeconomic literature in turn. Our analysis emerges from recent collaborative academic research by its authors, especially microeconometric research by Geruso and Spears (2018) and LoPalo (2018) about the consequences of heat and humidity in combination, and macroeconomic research by Budolfson et al. (2018)

about the dependence of optimal mitigation policy on the unknown future trajectory for economic development of poor, climate-vulnerable countries. But we are far from the first to raise these themes, and we build upon an accomplished literature at the intersection of environmental and development economics (Dennig et al. 2015; Edenhofer et al. 2014; Greenstone and Jack 2015; Hallegatte et al. 2016; Hijoka et al. 2014; Olsson et al. 2014).

Section 2 considers microeconometric evidence. It considers causally well-identified effect estimates of harms of climate exposure and uses them to project future damages within India under alternative possible futures for climate policy and outcomes. Section 3 presents macroeconomic projections. In this section, we make a novel application of the Regional Integrated Climate-Economy (RICE) climate-economy model, which was developed originally by the Yale University economist William Nordhaus (Nordhaus 1992, 2010; Nordhaus and Boyer 2000). As a global model that explicitly represents different nations, RICE includes assumptions, on the basis of scientific literature, that explicitly represent India's economy and quantify India's climate vulnerability. We use RICE to illustrate India's climate vulnerability by computing the magnitude of hypothetical near-term consumption losses to all Indians that would be an equal-sized loss to social welfare as climate damages. In other words, assuming a method for aggregating social harm across present and future Indians, what size of near-term economic disaster in the shape of consumption losses would be comparably bad as climate damages are projected to be? These results will be underestimates, because in using the RICE damage function, we conservatively ignore the new evidence of humidity-based damages in Section 2.

Section 4 briefly builds upon Greenstone et al.'s (2017) NCAER *India Policy Forum* study of air pollution. In contrast with climate damages, which will not fully unfold until future decades, India's population is already exposed to hazardous levels of air pollution today. The interaction between air pollution policy and carbon emissions policy is complex because particles in the air that harm human health can also reduce global warming by reflecting away sunlight. Recent analysis by Scovronick et al. (2019) considers the balance between these mechanisms: for India, the health damages from air pollution dominate the computation and offer a compelling reason to simultaneously reduce air pollution and carbon emissions.

Our focus is on understanding and quantifying the damages that India can expect in most of the paper. We turn to policy implications in the concluding section, that is, Section 5. What should Indian policymakers do in response to these grim facts? Elsewhere, we have considered the easier question of what the globally optimal policy would be. In Budolfson et al. (2019), we use the same RICE model to show that the best global emissions policy would take into account inequality in world economic development and the fact that richer countries are more capable of making emissions cuts. The globally impartial, welfare-maximizing policy would have the rich countries such as the USA very quickly decarbonizing, middle-income countries such as India phasing out carbon emissions more slowly over several decades into the 21st century, and the very poorest countries in sub-Saharan Africa perhaps continuing to produce some carbon emissions even in the early 22nd century.

But knowing what the globally optimal plan would be may provide little practical guidance to the leaders of India, or any other developing or middle-income country. Decades of highlighting the injustice of developed countries' emissions policies has done little to change them. Nor, as we show in Section 3, could India acting alone do much to reduce its own climate damages, even by entirely eliminating its carbon emissions. If India is to escape the climate damages that we project, it will require international policy change (in combination with appropriate and effective domestic investment by India in adaptation). Our findings highlight what others have also argued: India's leadership must approach the challenge of formulating a best response to climate injustice with an understanding informed by the sober facts of the vulnerability of its population.

2. Microeconomic Evidence: The Consequences of Heat and Humidity

In this section, we introduce empirical evidence from microeconometrics about the effects of temperature and humidity on outcomes such as health and productivity. We then compute the implications of these estimates for future Indians, where the combination of heat, humidity, and poverty—especially in the subtropical states of North India—comes together to create a unique context of climate vulnerability.

Temperature has been shown to affect many relevant outcomes, from human health, to crop yields, to the productivity of workers. Because researchers cannot observe the future climate, the only available research design is to compare populations and economies exposed to different weather outcomes (or the same population at different times). But simply comparing countries with hot climates to countries with cold climates to learn about the potential impact of climate change is problematic. Climate may be correlated with other variables that are otherwise correlated with economic outcomes. In this case, the researcher would misattribute the effect of these other variables to climate. To overcome such difficulties, an active literature in microeconomics uses short-term fluctuations in weather to make comparisons of outcomes on hot and cold days (or months) *within the same place*.

This strategy allows researchers to learn about the impact of temperature and other weather variables separate from other correlated factors (Dell et al. 2014). This literature has documented impacts of weather fluctuations on outcome variables such as conflict (Hsiang et al. 2013), health (e.g., Barreca et al. 2016; Deschenes et al. 2009), and productivity (e.g., Burke et al. 2015; Hsiang 2010). We demonstrate the implications of estimates from this literature for India by using data on current temperature distributions and projections of future weather under various climate change scenarios and the effect sizes from these studies. We note, however, that no empirical study of past consequences of exposure to the weather can fully uncover the possible adaptation that future populations could implement to reduce their exposure to harm. In that sense, these estimates underscore the potential benefits of effective adaptation.

2.1. The Under-appreciated Importance of Humidity

From a physiological standpoint, temperature is not the only weather variable that may be important for human well-being. One of the human body's main mechanisms for cooling itself is sweating, which lowers temperature through evaporation. Sweating is particularly important at high temperatures. Humidity significantly interferes with evaporative cooling: when the air is saturated with more moisture, sweat evaporates more slowly, meaning that the body is less able to cool itself. The results could be dire: when exposed to a combination of heat and humidity that is too extreme, the human body cannot cool itself because neither radiative cooling nor evaporative cooling from sweat will be successful. Under unlikely but feasible bad case scenarios for climate change, as Sherwood and Huber (2010) compute, high heat and humidity could make spending several hours outdoors literally deadly in much of the land surface of the world where humans currently live, including much of South Asia.

Recent econometric studies corroborate humidity as an important moderator of the effects of temperature on economic outcomes, even at less extreme levels of exposure. Barreca (2012) shows that hot and humid days are more dangerous than merely hot days in terms of health impacts in the USA. This has implications for the distribution of health outcomes: these results imply that mortality rates will increase more in hot and humid climates than in hot, dry climates as baseline temperatures increase. The literature on temperature and economic outcomes focuses primarily on developed countries, as data on both weather and outcome variables are more readily available in these contexts. However, this evidence suggests that it may be particularly important to understand the impacts of temperature in developing countries: developing countries are disproportionately located in hot and humid areas of the world. In addition, more people in developing countries work outside and fewer have access to adaptive technology such as air conditioning. For these reasons, developing countries are viewed as more vulnerable to the impact of humidity.

2.2. Climate Change and Infant Mortality

Motivated by this literature on human thermoregulation, several recent studies estimate the effects of heat, humidity, and their interaction in developing countries. Geruso and Spears (2018) merge Demographic and Health Survey (DHS) data on month of birth and timing of infant deaths with gridded global weather data in four continents. In each country, the DHS collects full reproductive histories from a nationally representative sample of women of reproductive age. These birth histories include the month of birth (and, when applicable, death) for each child, allowing the authors to match data on weather exposure to births occurring years before the interview. Because many babies are born in the same village in different years and months, their large sample of several million births (from every geographically coded DHS before 2015) allows the authors to identify mortality effects using surprise variation in the weather, while controlling for local seasonality, even specific to the village.

Like Sherwood and Huber, Geruso and Spears examine the impact of weather using a variable called “wet bulb temperature,” which is a (nonlinear) combination of temperature and humidity that gives a more complete portrait of outdoor conditions than temperature alone. In this literature, ordinary temperature is sometimes called “dry bulb temperature,” to distinguish it. Wet bulb temperature is the reading that would be given by a thermometer wrapped in a wet cloth; it is always lower than dry bulb temperature for relative humidity less than 100 percent. Geruso and Spears examine the impact of wet bulb temperature semiparametrically, estimating the impact of replacing a day with a 60–70° wet bulb temperature with a day in nine other bins. They find that hot and humid days in the month of birth predict significant increases in the probability of infant death.

Geruso and Spears estimate that an additional day in a month over 85° wet bulb (approximately 32°C at 80 percent humidity) predicts about half an additional infant death per 1,000 births. These extra infant deaths tend to occur in the first month of life, when neonates' bodies are still developing the ability to regulate their own temperature. In Figure 1, we apply the estimate derived from that study to Indian weather data in order to visually investigate the implications for climate change in India.

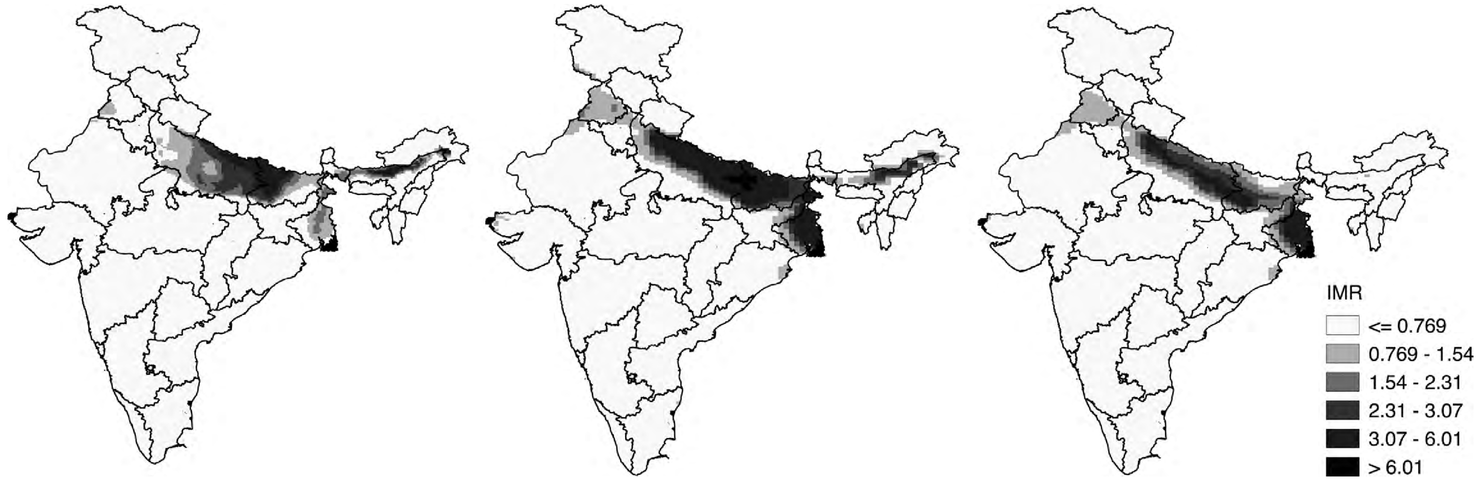
In Panel A of the figure, we first plot the *historical* implied effects, using average counts of experienced wet bulb degree days above 85° between 2000 and 2010. These weather data come from the Princeton Meteorological Forcing Dataset, which gives information on temperature, humidity, and other weather variables for every 0.25° latitude and longitude grid point.[1] We multiply this count by the implied annual effect size. The resulting distribution shows how much lower infant mortality rates per 1,000 births in 2000–2010 would have been in each location if the 85° days were replaced by 60–70° days. The figure shows that these extremely hot and humid days in India have been virtually restricted to the northern states of Uttar Pradesh and Bihar. Moreover, infant mortality rates would be as much as 7 per 1,000 births lower in the most impacted areas if the days over 85° wet bulb were replaced with mild days. This accounts for nearly 10 percent of the infant mortality rates in those regions during the period studied, a non-trivial fraction.

Panels B and C of Figure 1 project how climate change may alter the situation depicted in Panel A. Panel B uses projections of heat and humidity obtained from the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP). These data use the Hadley Centre Global Environmental Model (HadGEM2) to predict temperature, humidity, and pressure at a 1° latitude/longitude resolution. These types of projections generally categorize predictions into "Representative Concentration Pathways (RCPs)," which characterize different assumptions regarding the trajectory of future GHG concentration. Panel B uses predictions under RCP 8.5, a pessimistic scenario in which emissions continue to rise throughout the 21st century under assumptions of relatively high population growth and relatively slow income growth, technological change, and energy intensity improvements. Panel B shows the results of these projections for India by 2050.

This map uses the same method as Panel A: it shows the increase in infant mortality rate due to the number of days with wet bulb temperatures above 85° using the same effect sizes from Geruso and Spears (2018). Under this scenario, the ill effects of heat and humidity both spread to new areas in India and worsen in already affected areas. In addition to Uttar Pradesh

1. These data are derived from a combination of observational weather data from sources such as satellites, weather balloons, and stations with a physics-based model that extends the data to observationally sparse areas.

FIGURE 1. Infant Mortality Rate Increases from Extreme Weather



A: Historical Implied Increase in IMR

B: Business-as-usual Scenario (RCP 8.5) Increase in IMR

C: Aggressive Mitigation Scenario (RCP 2.6) Increase in IMR

Source: Princeton Global Meteorological Forcing Dataset; ISIMIP; Geruso and Spears (2018); and Authors' calculations.

and Bihar, Punjab and West Bengal become more severely affected by the types of hot and humid days that have been shown to affect infant mortality. Still, these types of hot and humid days will continue to be concentrated in northern India.

Panel C explicitly computes what is at stake when moving from a "business as usual" (BAU) climate outcome (RCP 8.5) to one requiring more aggressive climate mitigation (RCP 2.6) by showing the differential change in infant mortality under these scenarios. Under RCP 2.6, GHG concentrations peak mid-century and decline by 2100, representing an optimistic pathway for emissions. This differential infant mortality increase can be seen as the marginal cost of a bad climate outcome relative to a good climate outcome. Specifically, we calculate the excess number of 85° wet bulb days in 2050 under RCP 8.5 relative to RCP 2.6 and then calculate the increase in IMR using the same strategy (again, the thought exercise is the excess in IMR over a situation where the 85° days are replaced with 60–70° days). The result shows the excess IMR that could be prevented by achieving the RCP 2.6 pathway instead of RCP 8.5 and that the preventable deaths are largely concentrated in Uttar Pradesh, Bihar, and the eastern states.

All three panels show changes in infant mortality *rates* and therefore do not take into consideration the current population numbers or population projections in each place. However, these estimates indicate that these deaths will be taking place in some of the most populous regions in India; as of the 2011 Census, Uttar Pradesh was the most populous state while Bihar was the third most populous, together accounting for about a quarter of India's population. These two states also have the highest fertility rates in the country, implying that a large portion of future births will continue to occur in these especially climate-vulnerable regions.[2] Furthermore, Geruso and Spears find that measures of wealth in the DHS do not significantly mediate the impact of wet bulb temperature on mortality, suggesting that even wealthy people in developing countries may be unable to avoid some of the effects of extreme heat and humidity.[3]

2. Total fertility rates were 2.74 and 3.41 in Uttar Pradesh and Bihar, respectively, in the 2015–16 National Family Health Survey, in contrast to 1.83 in Andhra Pradesh.

3. Some prior literature has found that air conditioners moderated the mortality effects of high temperature in the 20th-century USA (Barreca et al. 2016). This is plausible here as well, in part because air conditioners also reduce humidity. Geruso and Spears cannot test for this, however, because they study developing countries where air conditioner ownership is sufficiently rare to be not measured in the DHS. In the 2005–06 India Human Development Survey (IHDS), only a small fraction of a percentage of households reported owning an air conditioner.

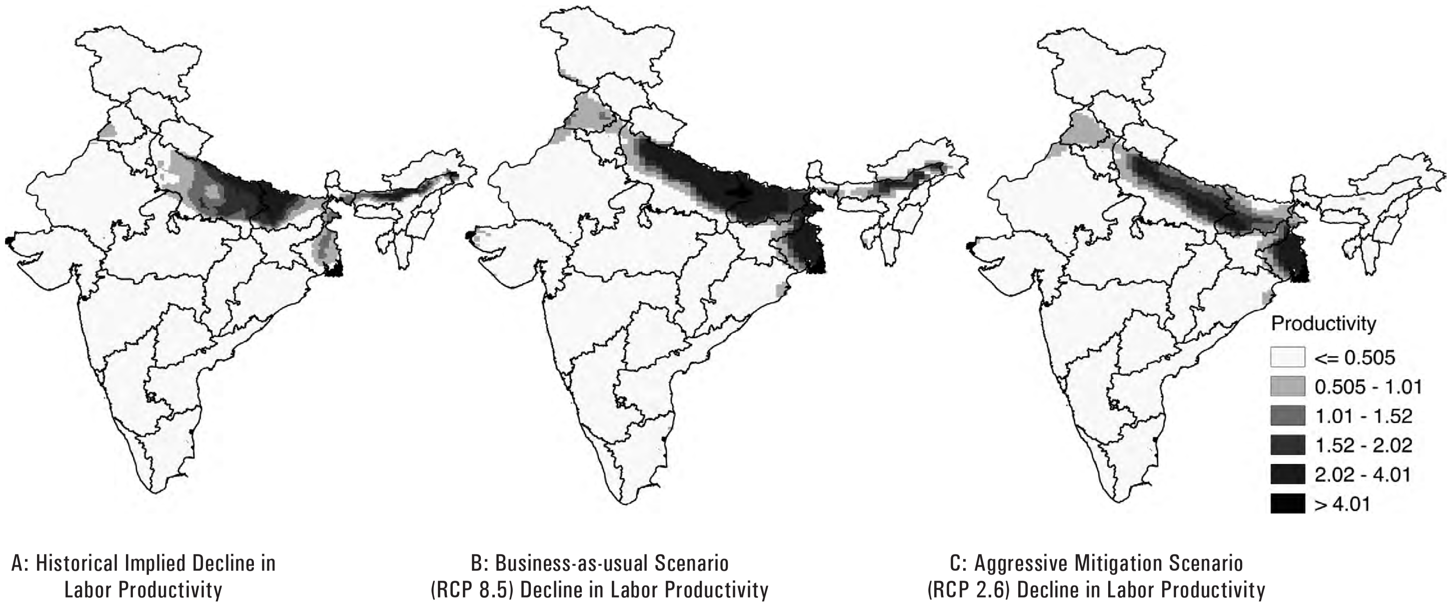
2.3. Climate Change and Labor Productivity

Infant mortality is an extreme form of climate vulnerability, but it is not the only relevant outcome likely to be affected by the increase in incidence of extremely hot and humid days. Another recent study suggests that this type of weather also significantly impacts labor productivity. LoPalo (2018) examines the impact of weather on a category of workers who are both significantly exposed to outdoor temperatures and possible to study using publicly available data: survey interviewers. In other words, LoPalo uses the DHS surveys to study the effects of exposure to the weather on enumerators *as workers*. She merges data from over 1.1 million interviews conducted in the DHS with data on temperature and humidity on the day of the interview and examines the impact of daily average wet bulb temperature on indicators of productivity such as number of interviews completed per hour worked as well as measures of data quality. Her analysis shows that, on days when wet bulb temperature exceeds 85°F, the number of interviews completed per hour declines by approximately 10 percent. The effects are driven by an increase in working hours rather than a decrease in interviews completed in a day; interviewing teams start earlier in the morning on these hot and humid days but do not complete their work earlier. She also finds that on hot days, the quality of work decreases: data quality problems are more common.

In Figure 2, we perform a similar exercise as in Figure 1, using the effects from LoPalo (2018). These maps plot the annualized estimate of the effect of temperature on productivity (number of interviews completed per hour in this case) multiplied by the number of high wet bulb days in each grid point. As in Figure 1, Panel A of Figure 2 depicts the impact of 85° wet bulb days under current distributions. It shows the impact that replacing each 85° day with a 60–70° day would have on annual productivity per hour. Panel B of Figure 2 shows the same estimates projected on future distributions of temperature under RCP 8.5. Note that the distribution of wet bulb days is precisely the same as in Figure 1; what has changed is that the scale is now interpretable as an effect on productivity, rather than infant mortality. Finally, Panel C of Figure 2 shows the difference in impacts on productivity per hour under the RCP 8.5 versus RCP 2.6 scenario. Again, these figures show that the greatest impacts will occur in the densely populated areas of Uttar Pradesh and Bihar as well as north-eastern India.

Infant mortality and labor productivity are only two examples of the wide range of outcomes that could be impacted by temperature. To get a full picture of the distribution of damages that could be caused by

FIGURE 2. Labor Productivity Decreases from Extreme Weather



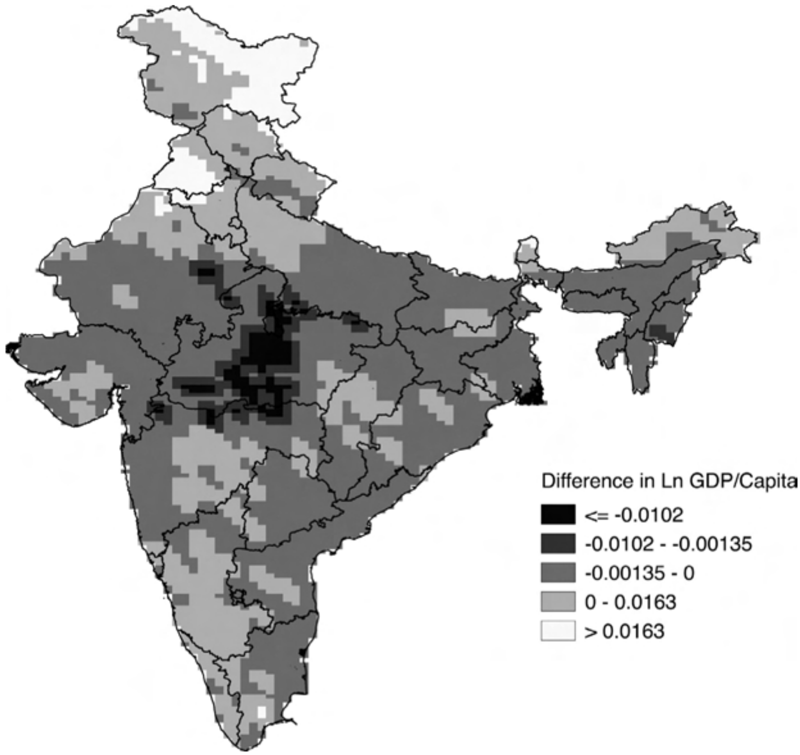
Source: Princeton Global Meteorological Forcing Dataset; ISIMIP; LoPalo (2018); and Authors' calculations.

climate change within India, it is also useful to consider the evidence on the impacts of temperature on GDP. Several papers have established correlations between climate and aggregate productivity as well as causal relationships between fluctuations in weather and measures such as GDP. One such paper is Burke et al. (2015), which estimates the impact of average annual (dry bulb) temperature on change in log GDP per capita using a panel of 166 countries from 1960 to 2010. Like other papers in the literature, they make comparisons within countries and difference out country-specific time trends. They find that production per capita is highest at around 13°C and declines sharply not only at higher temperatures but also at colder temperatures. They project these estimates to quantify damages under RCP 8.5. Colder regions such as Europe may see productivity benefits under climate change, but regions that are warmer on average experience large damages.

Burke et al. also conducted a country-by-country exercise to examine the implications of climate change for individual contexts. India is one of the most severely affected countries in the world by their estimates. We use their estimates to conduct an additional exercise to visualize the implied distribution of effects *within* India. In Figure 3, we implement a simplified calculation to show differences in growth rates that might be expected under RCP 8.5 versus 2.6. For this illustration, we assume that local GDP per capita growth is determined only by annual average temperature, as estimated in Burke et al. We then calculate the changes implied by the projected average temperature in 2050 under RCP 8.5 and 2.6, respectively. Finally, we calculate the difference between the two rates, giving an idea of the distribution of impacts on GDP growth under the two emissions scenarios. The results suggest that the majority of India will be negatively affected under RCP 8.5 relative to RCP 2.6, with Madhya Pradesh especially impacted. The white and light gray areas in the map signify regions that will be positively impacted by warming: this occurs for areas with an annual average temperature of less than 13°C.

A consistent theme across these results is that India is deeply vulnerable to global warming given the humid climate of South Asia. Within India, climate damages will tend to be greater in the places where the population is already more disadvantaged: we find that Uttar Pradesh, Bihar, Madhya Pradesh, and neighboring states tend to show more vulnerability in the projections presented earlier. Given current inequities, climate damages will not merely reduce the average well-being of the future Indian population; they are also projected to increase inequality by falling disproportionately on the most disadvantaged within India.

FIGURE 3. GDP Changes from Global Warming



Source: ISIMIP; Burke et al. (2015); and Authors' calculations.

3. Macroeconomic Projections: How Much Are Climate Damages Worth?

Section 2 documented that many important economic and social indicators are vulnerable to temperature and humidity. However, a critical question remains: How does one weigh these costs in total? How should policymakers aggregate the consequences of climate policy for the full Indian population, including people alive today and people who will not be born for decades to come?

To answer this question, we develop an India-centric Integrated Assessment Model (IAM) by modifying a global IAM in wide use in the climate policy literature. We modify William Nordhaus' RICE model. Because RICE considers only (dry bulb) temperature, not humidity, this section does too. The evidence in Section 2 suggests that these results will, therefore, underestimate India's climate vulnerability. Despite this, the model projects total Indian climate damages to be extremely large. Quantitatively, the damages under the case of no global GHG reductions are as costly—in a well-being sense—as a hypothetical reduction in GDP per capita of 25–30 percent for each of the next 20 years. An event of this magnitude would be a humanitarian disaster. However, as the model shows, these damages cannot be avoided by a reduction in India's emissions alone.

3.1 Overview of IAMs

IAMs are macroeconomic growth models with a climate component designed to quantify the economic trade-offs associated with carbon emissions. The most widely used IAMs (DICE/RICE, PAGE, and FUND) share the same conceptual structure (Hope 2011; Nordhaus 2017, 2010; Tol 1999). Economic production/consumption generates well-being for the people who consume, but also results in GHG emissions. GHG emissions enter a climate module designed to track the stock of CO_2 and the resulting global temperature dynamics. Higher future temperatures then cause harm to future people according to a relationship called the *damage function*.

To measure these trade-offs in a way that assesses the consequences for everyone, we use a standard social welfare function (SWF) that is additive across time. Equation (1) formalizes this.

$$W(c;\rho,\ L) = \sum_{t=0}^{Z} \frac{1}{(1+\rho)^t} L_t U(c_t) \tag{1}$$

Total social welfare is the sum of utility in each period from today (t = 0) until some end date (t = Z) generated by per capita consumption, $U(c_t)$ multiplied by the population in that time, L_t, and discounted by $\frac{1}{(1+\rho)^t}$, which is a factor that makes future costs and benefits worth less to the social evaluation than nearer term costs and benefits.[4]

Temperature, T_t, does not enter the SWF directly because the IAM is constructed to deduct climate damages directly from the output available for economic use.

$$Y_t^N = (1 - D(T_t))Y_t^G \tag{2}$$

4. The utility function is assumed to have diminishing marginal returns, specifically of the constant relative risk aversion form: $\frac{c^{1-\eta}}{1-\eta}$, where η is the inequality aversion factor.

Equation (2) defines net output in each period, Y_t^N, as some fraction of gross output, Y_t^G. The fraction lost, $D(T_t)$, is the damage function. This functional form implies that some output is either spent in adaptation efforts (and is therefore unavailable for consumption) or is destroyed from high temperatures. The idea of temperature directly destroying output may be difficult to conceptualize, but it approximates two more realistic interpretations: (a) that more inputs are needed for the same level of output (productivity declines) or (b) that more output is necessary to retain the same utility level (agents need to be compensated for the higher temperatures).[5]

We are interested in the trade-offs relevant for an Indian policymaker, so Equations (1) and (2) include only Indian inputs. For example, (1) is an India-specific SWF with projected Indian population and per capita consumption in each scenario. Climate damages are losses to total Indian consumption from a warmer planet. Costs and benefits for people living outside of India are not counted.

3.2. Social Costs of Emissions in an IAM

In building toward aggregate damages, we start with a decomposition of the social cost of an extra ton of GHG emissions. This quantity is known as the social cost of carbon (the SCC). This decomposition has a convenient multiplicative form that allows us to highlight each potential channel for damages to increase or decrease. The most uncertain and contested of these channels are the damage function and the social discount rate. We take extra care in discussing these further.

Mathematically, the SCC can be shown to be of the form presented in Equation (3) (Golosov et al. 2014).

$$SCC = \sum_{t=0}^{\infty} \frac{1}{(1+\rho)^t} L_t \frac{\Delta U(c_t)}{\Delta c_t} \frac{\Delta c_t}{\Delta T_t} \frac{\Delta T_t}{\Delta E_0} \qquad (3)$$

The complex economic and atmospheric relationships we hope to capture can be simplified conceptually into five multiplicative terms (here we use the notation $\frac{\Delta y}{\Delta x}$ for the change (Δ) in y that results from a one-unit change in x).

i. $\frac{1}{(1+\rho)^t}$: Pure social discount rate

5. This second interpretation is not exact because some fraction is saved rather than consumed, but it is close enough for expositional purposes.

ii. L_t: Population in time t

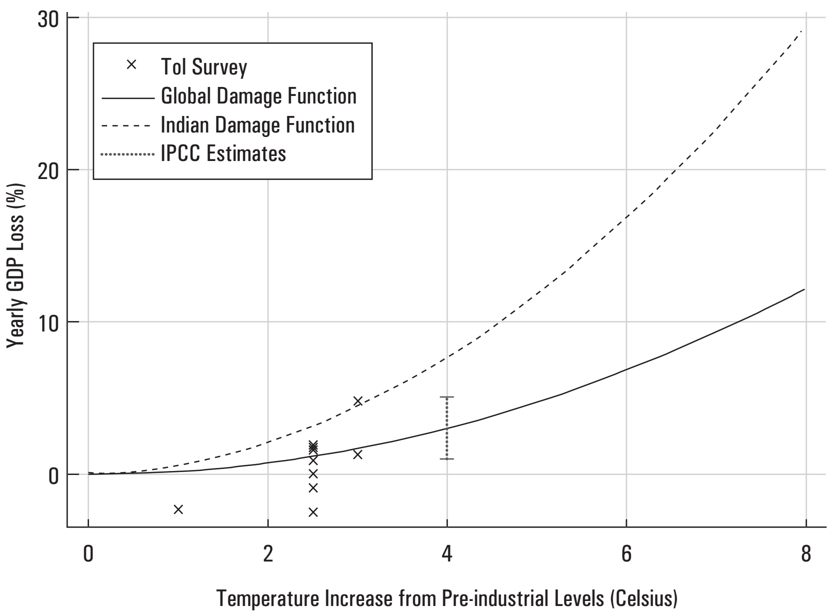
iii. $\frac{\Delta U(c_t)}{\Delta c_t}$: Increase in utility that results from an extra unit of per capita consumption

iv. $\frac{\Delta c_t}{\Delta T_t}$: Consumption equivalent losses that result from an increase in temperature at time t (the damage function)

v. $\frac{\Delta T_t}{\Delta E_0}$: Increase in temperature at time t that results from an extra unit of GHG emissions *today*

In this paper, population projections are taken from the United Nations World Population Prospects. The Indian damage function that we use (term iv above) was derived by Nordhaus (2010) by scaling up a global damage function to reflect a consensus that India is more vulnerable than a globally averaged damage function would imply. As documented in Nordhaus and Sztorc (2013) (and replicated in Figure 4), the global damage function is

FIGURE 4. Global and Indian Damage Functions



Source: Nordhaus and Sztorc (2013); Tol (2009).

fit to the meta-analysis of Tol (2009).[6] The fitted function is restricted to be quadratic and is calibrated over a range of estimates from 1° to 3° of warming.[7] India's damage function then takes the same functional form but lies above the global function at all points.

A challenge present throughout the IAM literature is that it is especially difficult to know how costly climate damages would be beyond 3°C of warming. We continue to follow Nordhaus (2010) by assuming the calibration at lower temperatures remains informative at higher temperatures. This results in substantial—yet unavoidable—uncertainty over a range of potential outcomes. Subsequent work suggests this uncertainty is one-sided: the DICE/RICE damage function used here is very likely a *lower bound* for damages at high levels of warming.[8] Specifically, Weitzman (2012) presents a convincing case that the DICE/RICE implied damages are implausibly low for warming greater than 3°. Likewise, Burke et al. (2015) estimate damages using a method less reliant on extrapolation and find a South Asian damage function nearly an order of magnitude larger than what we use here. Nordhaus (2017) himself has even adjusted damages upward in his most recent work.[9]

Beyond this, no damage function in the IAM literature—including the Nordhaus (2010) specification that we use—considers increases in *wet bulb* temperature. As documented in Section 2, the importance of humidity makes India more climate-vulnerable (relative to drier developing regions such as sub-Saharan Africa) in a way that has been previously omitted. In order to be grounded in the prior literature, our damage function, too, omits the potentially important role of humidity. Therefore, although the damage function remains a highly uncertain object, we are confident that our striking results are not driven by unrealistically pessimistic assumptions regarding the damages of climate change.

Terms (i) and (ii) of the SCC quantify the relative importance of damages faced by further-future people compared with damages faced by nearer-future people. These terms reflect the two justifications for discounting over time: (a) because damages occur in the future, and (b) because damages are suffered by richer populations in the future. Some combination of

6. The damage estimates in Tol (2009) are designed to include the monetary costs of optimal adaptation as well as the costs of lost output/well-being. For example, the costs of sea-level rise include the cost of building dikes and levees where possible (adaptation) and the cost of damaged/lost landmass where not (residual damages).

7. While only calibrated on 1–3°, the damage function sits in the IPCC range of estimates for 4°.

8. See Diaz and Moore (2017) for an extensive review of aggregate IAM damage functions.

9. We use the Nordhaus (2010) version because it is a disaggregated model which allows us to pull India's damage function directly.

these two factors determines how much we ought to value losses to future populations.[10] This is important for our analysis because climate damages will unfold over coming centuries. A large body of literature in climate economics has recognized that optimal mitigation policy is substantially shaped by the choice of a discount rate: if the social evaluation assumes that the future does not matter, then it is unsurprising that models recommend unaggressive climate mitigation policy. Understanding the respective roles of these parameters is then critical to understanding our results. To reiterate, term (i) plays a simple role of discounting *well-being* just because it is experienced at a later date. The way term (ii) influences discounting, however, is less obvious.[11]

Term (iii) is the marginal utility of an additional unit of consumption. It is an uncontroversial consensus among social scientists that this changes with income: adding $1 to the budget of a poor person increases his/her well-being more than if we did the same for a richer person.[12] Throughout this literature, economists use functions in which a single parameter, η, controls the importance of extra money to a poorer person, relative to a richer person. This parameter is known as the “inequality aversion” of the model. Inequality aversion is important for discounting in climate policy if we expect future economic growth: because future Indians will be richer than present-day Indians, future money losses are less important to policymakers than today’s money losses to a poorer population.

3.3. Social Welfare Parameter Choices

There is a large body of literature documenting that differences in discount rates drive many of the academic disagreements on climate policy (Broome 2012; Dasgupta 2008; Greaves 2018; Nordhaus 2007; Stern 2006; Weitzman 2007). After careful review of this past work, we have come to agree with the authors who believe that total discounting cannot and should not be inferred from individual economic choices. In our view, ρ reflects the ethical choice

10. The exact way these come together to determine the *total discount factor*, δ, under a constant rate of economic growth, g, is represented by the well-known *Ramsey Equation*:

$$\delta = \rho + \eta g$$

11. Well-being is emphasized because ρ is a discount on utility, not goods. It may be reasonable (as we discuss in the following paragraph) to discount damages to future people because they will be wealthier, but this has nothing to do with ρ.

12. Nordhaus (2010) and other regionally disaggregated climate-economy models use a solution technique called “Negishi weights,” which results in a SWF that does not respect this cross-sectionally—$1 to a rich person is as socially valuable as $1 to a poorer person. We interpret Negishi weights as an attempt to solve for the model’s equilibrium, rather than a rejection of cross-sectional diminishing returns.

of policymakers: are future Indians as important as present-day Indians? In contrast, inequality aversion η is, in principle, empirical: it reflects how human well-being increases with increasing levels of consumption. This parameter is unfortunately impossible to estimate in practice.

Therefore, as in essentially every study in the IAM literature, we choose baseline values of ρ and η, and present robustness checks with other values. We believe the appropriate choice of ρ is 0.[13] The list of authors that agree with this choice is long,[14] and it follows from a simple argument that in the SWF, all Indians, regardless of year of birth, matter equally. Suffering is no less bad whether it occurs 50 or 100 years from now merely because one is further away from us in time.

The parameter that governs the rate of change of marginal utility, η, stands on less firm grounding. We choose a level to match our prior work in Budolfson et al. (2018). To understand the baseline parameter we choose, $\eta = 2$, consider two people, one twice as rich as the other. If the poorer person realizes some consumption gain, our baseline value of η implies that the wealthier person would need to receive *four times* that gain for it to be as socially good. Zero inequality aversion, in contrast, would imply the richer person would just need the same monetary gain for it to be as socially good, an implication we find implausible. Because any choice is subject to disagreement, we will present robustness checks with additional η values that correspond to the income gains needing to be 2.5 and 5.5 times as large, respectively, rather than the original 4.[15]

3.4. Quantitative Results

We can now quantify aggregate damages to India from climate change using the model and parameters just described. These damages are large, even though they do not include the humidity interactions described in Section 2.

We quantify damages from climate change in terms of consumption-equivalent losses to current people: by what percent would per capita

13. In practice, some very small positive number is used to follow Stern (2006) who makes an adjustment for the exogenous risk of extinction.

14. Cowen and Parfit (1992), Stern (2006), Dasgupta (2008), and Broome (2012) are some notable examples.

15. The main objection to our resulting discount factor is that an individual's saving behavior does not match what would be implied by the discount rate on goods we are using. We are not bothered by this. Even if we believed the SWF should be democratically determined (i.e., correspond with individual preferences), saving decisions reflect how individuals plan to allocate their resources to their own individual futures. Personal impatience is a different consideration from how society values the lives of future generations.

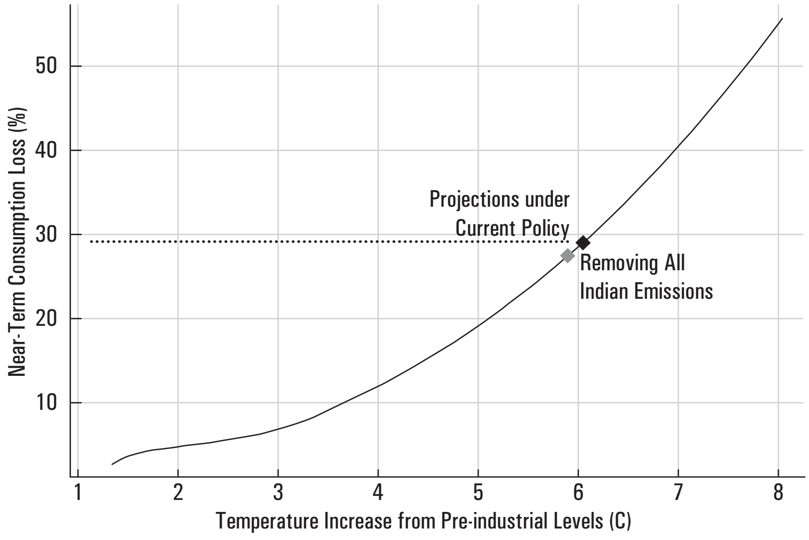
consumption need to be reduced for the next 20 years to match the total welfare losses associated with climate change? What reduction in near-term consumption would be just as bad, from the point of view of the SWF, as climate damages will be? Preventing a deep and sustained economic collapse would presumably always be a top policy priority, so this is a useful way to calibrate the policy importance of climate damages.

In particular, the consumption loss that would be equivalent to climate damages is calculated as follows:

- Step 1: Exogenously warm the planet and compute India's total well-being for all future periods under the resulting level of global warming.
- Step 2: Re-run this scenario without climate damages and instead reduce per capita consumption for the first 20 years until total well-being from Step 1 is matched.
- Repeat Step 1 and Step 2 for various possible global warming scenarios.

Without any further global mitigation policy, the economic collapse necessary to match projected climate damages is a 29 percent reduction in GDP per capita for each of the next 20 years. This would be a catastrophic loss. Figure 5 presents these near-term consumption equivalent damages under the baseline choices of $\rho = 0$ and $\eta = 2$ for a wide range of potential climate outcomes.

FIGURE 5. Near-Term Consumption Equivalent Losses



Source: Authors' calculations.

As shown in Figure 5, these damages have the potential to be extremely large. The rightmost point labelled on the curve corresponds to the global BAU scenario in DICE: no GHG restrictions are enacted beyond current policy, and mitigation comes only from private sector technological developments.[16] Under this outcome, many decades of the Indian population would experience climate damages amounting to about 15 percent of GDP.

Perhaps more important than the large *level* of damages is the *slope* of this function. At high levels of warming, changes in global temperature cause very large changes in Indian well-being. For instance, the planet is projected to warm by around 3.5° if the national emissions pledges in the Paris Accord are successfully realized (Reilly et al. 2015). Climate damages would be cut by two-thirds despite warming being reduced by less than one half. Global efforts to reduce warming are especially valuable to India in light of this damage convexity.

A natural reaction to this quantification of India's climate vulnerability may be to suggest that India should quickly and unilaterally decarbonize. The RICE model also allows us to assess the consequences of such a policy. For better or worse, over the coming decades, India's emissions are projected to remain a small fraction of the global, historical stock of GHG emissions. The dot to the left in Figure 5 shows that the peak global temperature would decrease only slightly if India were to altogether eliminate its emissions. As a result, its climate damages would only slightly decrease. The global temperature would probably decrease by even less than shown in the figure because we do not model an endogenous response of other countries: India removing itself from aggregate energy demand would reduce prices and increase other countries' energy use. The message of the RICE model is clear: India is highly vulnerable to climate damages and cannot eliminate the problem by reducing its own emissions.

3.5. Robustness

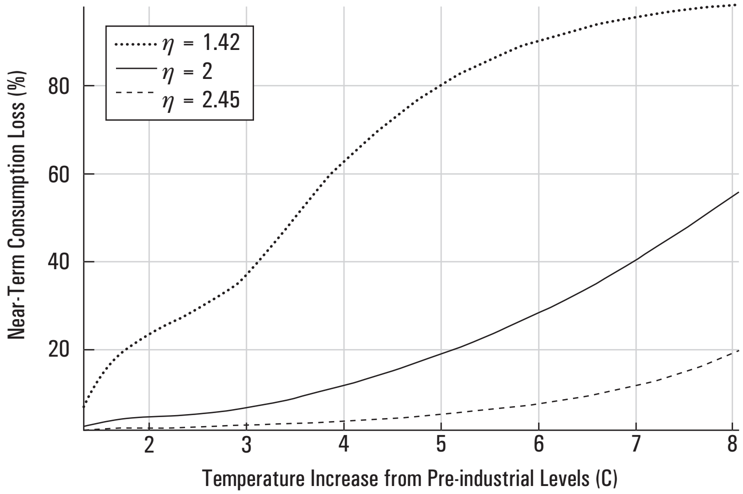
Given the well-known importance and uncertainty over how to discount future costs, we report the robustness of our results to alternative choices of the inequality aversion η.[17] Figure 6 plots how the results change with these higher and lower values of inequality aversion.[18]

16. This corresponds closely to the RCP 8.5 scenario.

17. As we feel much more confident in our choice of ρ, we believe this uncertainty is the result of not knowing how fast individual (and social) marginal returns to income diminish.

18. See the paragraph directly preceding this "Results" section for the discussion of η values chosen for sensitivity checks.

FIGURE 6. Robustness to Alternative Inequality Aversion Assumptions



Source: Authors' calculations.

Because the model assumes that future Indians will be substantially richer than present-day Indians, changes to η are extremely influential for how bad climate damages are perceived to be.[19] Using smaller values of η (1.42 in this case) pushes the damages to very high levels (over 80 percent for 6°C of warming). But if η is large (2.45 here), total damages become notably smaller. In fact, this graph is conceptually bounded between 0 and 100 so these values span nearly the entire set of feasible outcomes. The fact that the results are heavily shaped by the choice of η is consistent with observations in Dasgupta (2008). However, our choice of η is not low relative to practice in the climate-economy literature so we take little comfort in the low damages associated with an unusually high value of η.[20] This is especially true given the conservative damage function we use.

19. Assuming otherwise—that India will not experience rapid economic growth—would make climate damages even more important to social welfare because a poorer future population would experience the harm.

20. Although Dasgupta (2008) urges authors to consider larger values for this parameter, the most influential IAM results (Nordhaus 2010; 2017; Stern 2006) all use a value less than 2 (some going as low as 1). Micro evidence supports our choice as well: Carlsson, Daruvala, and Johansson-Stenman (2005) use hypothetical survey questions about the well-being of grandchildren and estimate η to be 2 for intergenerational inequality. Studies directly using governmental behavior in tax policy to infer η in other policymaking spheres find values between 1.3 and 2 (Cowell and Gardiner 1999; Stern 1977). See Dasgupta (2008) and Greaves (2018) for reviews on total social discounting.

4. Health Co-Benefits

Although the focus of this paper is on climate vulnerability, this section introduces an important near-term vulnerability of the Indian population with impacts for climate policy: air pollution. Reductions in GHG emissions tend to lead to reductions in air pollutants, because both pollutants tend to share common emission sources (e.g. coal-fired power plants [Gupta and Spears 2017]). As a result, reductions in GHG emissions are likely to lead to improvements in *current* human health through improved air quality. These benefits are often called health "co-benefits" because they are additional benefits that come alongside the direct climate-related benefits of GHG reductions. Emerging research suggests that these health co-benefits may be large, especially for a nation such as India in which air pollution is one of the nation's leading health problems. For example, according to recent data from the World Health Organization, 14 of the top 20 cities with the highest levels of particulate matter pollution in the world are in India (BBC 2018). Interestingly, these cities are all located in northern India, the same region with the highest level of population, fertility, and climate vulnerability in the country: seven of these 20 globally-most-polluted cities are in Uttar Pradesh and Bihar.

Thus, health co-benefits have a critical place within India's climate policy decision-making and are an additional source of benefits for India from GHG reductions. This is in part because large benefits occur quickly enough to be economically important even with high time discount rates: air pollution is already harming the population alive today (Scovronick et al. 2019). Furthermore—and of particular importance to Indian policymaking—these health co-benefits of GHG reductions can be almost fully captured by a large country such as India through unilateral domestic policymaking, as most co-benefits are realized domestically (in contrast to the fully globally dispersed climate-related benefits of GHG reductions). Co-benefits are also not as vulnerable to being negated by the non-cooperative economic and policy response of other nations (in contrast to climate benefits, which are vulnerable to "emissions leakage," as discussed further, and can also represent a transfer of GDP from the mitigating nation to other non-cooperative nations).

Globally, the benefits from preventing air pollution-related deaths alone may outweigh the mitigation costs of reducing carbon emissions. Shindell et al. (2018) examine the local health impacts of reducing emissions enough in the 21st century to achieve 1.5° warming rather than 2°, finding that the drop in air pollution could prevent around 150 million premature deaths, mostly in Asia and Africa. They estimate the health impacts in individual metropolitan areas, showing that Indian metros such as Kolkata, Delhi, Mumbai, and Lucknow will be among the top beneficiaries in terms of number of avoided deaths. Similarly, Markandya et al. (2018) find that in some mitigation strategies, co-benefits of carbon emission reductions were almost double the costs in some areas, implying that mitigating enough to achieve 1.5° warming would have a net benefit for India, as well as China. Scovronick et al. (2019) find that optimal global mitigation results in immediate net benefits when climate costs, climate benefits, and co-benefits and co-costs are all jointly considered.

A large literature, recently surveyed by Greenstone et al. (2017), highlights the large costs of air pollution to the health of Indians and people in other emerging nations. Among the reasons for these costs, burning coal may be especially important. For example, Gupta and Spears (2017) estimate the impact of coal plants in India on the health of people living in the same district by studying districts where a new coal plant opened between the 2005 and 2012 waves of the IHDS. Because the survey visited the same households at the beginning and end of the seven-year interval, Gupta and Spears can show that reported respiratory health worsened over time in the districts that acquired a coal plant, relative to the districts that did not. Tellingly, the result is respiratory specific: diarrhea and fever were unaffected. Moreover, other types of new power plants—such as solar or hydroelectric—are not associated with worsening health, which rules out that the result is spuriously due to electrification or economic activity.

One reason that air pollution is so harmful is that the impacts extend to essentially everybody and are almost impossible to escape. In a recent South Delhi winter, Vyas et al. (2016) conducted an experiment regarding potential avoidance of these harms in an upper middle-class flat in Green Park. They used air quality monitors to test the effectiveness of commercially available air filters.[21] Under ideal conditions—never opening room doors, even to the interior of the house—the filters made a difference, but much pollution remained. Under a reasonably normal schedule of opening doors, much of what the filters achieved was erased. Part of the problem—reflected in the fact that indoor air quality remained highly correlated with outdoor air quality—is that even upper middle-class flats in privileged neighborhoods often do not have window frames and door frames that prevent air from circulating. Perhaps unlike other contexts, such as drinking water pollution, even rich Indians have little scope for buying their way out of air pollution.

21. These included both a relatively affordable filter and an expensive one.

In recent research, Scovronick et al. (2019) modify the same RICE model that we used in Section 3 to incorporate an air pollution module. Their objective is to optimize mitigation policy while considering both climate damages and the near-term harm to health from air pollution. The optimal policy balances countervailing forces: air pollution can be cooling, as particles reflect sunlight away from the earth. They find that the health co-benefits dominate and recommend more rapid climate mitigation than if air pollution were ignored. Indeed, once health benefits are co-considered, it may be globally economically optimal to limit temperature rise to approximately 2°C. This finding is especially relevant for India, where severe health costs of pollution are the inverse of considerable health co-benefits. Their result suggests that health co-benefits could even make aggressive mitigation policy rational for India on its own.

5. Conclusion: India's Best Policy Response to Climate Injustice

Our quantifications show that India is highly vulnerable to climate damage. Our baseline macroeconomic approach suggests that climate change peaking at 5°C, rather than 3°C, would be as detrimental to Indian well-being as a reduction in GDP by 17.5 percent for each year from 2020 to 2040. Our microeconomic results suggest that even this may be an underestimate because it ignores the humidity of South Asia. Clearly, such a threat to near-term economic outcomes would be an overriding policy priority if political leaders anticipated it. If so, India's climate vulnerability should be a top priority too.

What is India's best response to these facts? As we have argued elsewhere, the Intended Nationally Determined Contributions that richer polluters (such as the USA and the EU) have submitted under the Paris Agreement are inadequate, inequitable, and unjust (Budolfson et al. 2019). We believe that the richer countries should substantially reduce their emissions—quickly and without receiving anything in return—and should substantially fund the climate mitigation and adaptation of poorer countries. But what should India do if they do not, as will presumably be the case?

There is no easy answer to this question. Faced with the dilemmas of international cooperation, some analysts suggest that India should "do it alone": either unilaterally eliminate/reduce its GHG emissions, or, oppositely, pollute as much as necessary to get rich enough to reduce its vulnerability to climate damages.

But India cannot do it alone and reduce emissions enough to escape. One reason is limits to state capacity of the sort that many developing countries face. As Greenstone et al. (2017) summarized in their seminal NCAER *India Policy Forum* paper:

> A necessary requirement for command-and-control regulation to work is a very well-informed regulator with the willingness and ability to systematically enforce fair penalties in cases of non-compliance. In the main, this has been lacking in India. Duflo et al. (2013) show how reliable data can be an elusive goal, and Ghosh (2015) identifies severe weaknesses in the enforcement mechanism.

Coffey and Spears (2017) make similar observations about a high-profile rural sanitation program: behavior change is difficult to promote; the small personnel per capita size of the Indian state limits capacity; and official statistics can be unreliable even on matters that are routinely measured by straightforward demographic surveys. Muralidharan's (2016) NCAER *India Policy Forum* paper on public employment touches on some root causes and potential solutions to these issues of personnel and capacity. However, developing and promulgating sophisticated and detailed guidelines for the optimal regulation of emissions might, in this context, waste valuable time while having little impact.

The larger reason that India's emissions reductions would be inadequate is that there simply are not enough of them to tip the scales: as we computed in Section 3, even if India hypothetically fully eliminated its emissions while the rest of the world did nothing, it would still face almost as many degrees of warming. Worse still, it is unlikely that the rest of the world would be unaffected by India's unilateral decarbonization. Instead, India, removing itself from global aggregate demand for fossil fuels, might end up lowering the price of carbon, so that some of India's emissions reductions could be offset by increases in other countries, often called "emissions leakage."

Nor can India do it alone and escape through unrestrained GHG emissions to accelerate development. That is because the numbers do not realistically add up. Emissions are valuable, but they are not valuable enough to promote the economic growth necessary to enable India to escape via this strategy.

Therefore, India's best response to climate injustice may be first and foremost foreign policy, as well as domestic economic and health policy. The reason the question of what India should do is so challenging is that it depends on India's power to influence other countries' emissions.

It's worth noting, however, that the fact that India cannot unilaterally mitigate its vulnerability to climate change does not imply that it would not be individually rational for India to dramatically reduce emissions. As we discussed in Section 4, recent evidence suggests that the current health burden of air pollution, which is particularly heavy in India, justifies significant mitigation of emissions independent of the climate benefits. While the concern of emissions leakage applies to this strategy, if India mitigated emissions to a level that would be optimal only considering health co-benefits, the leadership that India would be taking in reducing its own deep vulnerability to damages from air pollution may give it more leverage to convince other international players to take action, putting the world on a path toward reduced warming.

Another possibility—suggested by the large size of India's climate damages—is that India may have the option of achieving its climate policy goals via strategic international interactions that accept a creative concession in other sectors of policymaking in order to achieve reductions in the emissions of richer countries. We make no suggestions about what sort of non-climate concession (perhaps even a non-economic, symbolic concession) would be effective to offer; we merely note that India's climate vulnerability unfortunately suggests that a Pareto improvement could perhaps be found in the right packaging of a non-emissions concession from India, combined with large emissions sacrifices from rich countries. How might such a package be invented?

Perhaps one desirable feature is to engineer such a package to have time consistency between the concessions India makes and the emissions reductions that developed nations make with antecedently agreed mechanisms for monitoring and adjustment in light of each side's subsequent compliance. For example, one can imagine trade concessions from India in exchange for deep emissions reductions, where the continuation of those concessions is contingent on reciprocal compliance. Or, perhaps the right package involves a concession in symbolic diplomacy, security policy, or another dimension of international politics—with the concession explicitly linked to and contingent on emissions reductions from China, USA, the EU, and perhaps others. Or perhaps a different package altogether is the best—the point is merely to illustrate that opportunities may exist for multilateral agreements between India and other nations that have desirable properties.

Inventing the right concession to offer would be only one challenge. Such a strategic concession would only make sense if high-emissions developed countries are sufficiently rational actors in international politics that they could be bargained with; perhaps they are not. The success of such a scheme would require international monitoring of rich country agreements, so India can be sure it is getting what it bargained for. Efforts to create such monitoring standards should therefore be fully embraced by India. Even in the absence of an agreement between India and high-emission countries, it is to India's benefit that these data be transparently and consistently collected: its vulnerability and low emissions per capita result in it having much to gain and little to lose. Calls for credibility in GHG accounting may constitute a new reason that it would be in the interests of the Indian state to contribute to a norm of accurate official statistics.

It would be a moral tragedy if India must make such a strategic concession to protect Indians from the unjust emissions of rich nations. But climate change involves moral tragedies. If either (or both) strategic concessions or immediate health-improving emissions reductions are possible and required to slow global GHG emissions, it would be a mistake for India not to do at least what is in the interest of present and future Indians to protect them from the grave threat posed by unbridled climate change.

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Comments and Discussion*

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I really enjoyed reading this paper. I am going to try to do three things. I am going to leave the econometrics to Professor Shreekant Gupta, but I am going to try and talk first about the policy context for the paper. What policy conversations are these authors trying to engage in? Then, second, how robust are the conclusions, and third, should we buy the conclusions?

Why this paper? I read the paper in the context in which it is hard to get people in India to focus on climate change. So I have somewhat provocatively called climate change in India as a policy and political backwater. If you are a part of policy conversations in India and you talk about climate change, then the few stock reactions all lead to the conclusion that India shouldn't really pay a lot of attention to climate change. One stock reaction is that we have a lot of other immediate issues that with guaranteed certainty are doing more harm. Just to pick an issue at random, there is sanitation, where Dean Spears and Diane Coffey (2017) have made a very compelling case, putting numbers and qualitative information about why we should worry about sanitation right now. Another stock reaction is the climate justice story, which says that since the North caused this problem, why should we focus our policy attention on this? Then there is the argument that growth allows better adaptation, and since mitigation would only constrain growth, mitigation therefore works against our interests, even on climate change.

So we have this strange situation in which India is one of the countries most vulnerable to climate change and globally we have this discussion about an existential crisis. But within India, it is extremely hard to gain much political attention for climate change other than episodically between November 5 and December 5 when the annual Conference of the Parties (COP) to the 1992

* To preserve the sense of the discussions at the India Policy Forum, these discussants' comments reflect the views expressed at the IPF and do not necessarily take into account revisions to the conference version of the paper in response to these and other comments in preparing the final, revised version published in this volume. The original conference version of the paper is available on www.ncaer.org.

United Nations Framework Convention on Climate Change happens in one of the global capitals of the world.

So I see this paper as being part of a larger conversation about how we can steer climate change out of this kind of backwater. I think Kevin Kuruc put it very bluntly. If we can put up a big GDP number up there that gets people's attention, or if we can hitch this wagon to an engine that has more momentum and can bring in issues and communities that already command attention—infant mortality, labor productivity, air quality, using the examples from this paper—then we can get somewhere. So I see this paper in the context of how to get attention to this issue.

So what are the answers provided by the paper? The paper argues that climate change-related temperature changes can increase infant mortality, decrease labor productivity, and lower GDP per capita. The big, headline number is 29 percent GDP per capita decline for 20 years. Besides avoiding these losses, the air quality benefits of dealing with climate change are considerable. These are all compelling arguments. Then the question is: Do they hold up? Before actually getting to this, let me just say that if this is indeed a correct reading of the paper; it is a view I am very sympathetic to. My questioning of whether the paper has achieved this goal is by way of strengthening its arguments, because I think this is a worthy objective to achieve.

So here are some questions that I have. On the microeconomic evidence, the question is whether data from within-place variations across time capture the kind of climatic discontinuities that we expect to see from climate change? Melissa LoPalo in her presentation said that, in fact, they can't. I think she was right to put that caveat, but I would note that this actually strengthens their case that this is only a floor level of impact. So it is a useful set of arguments.

The authors refer to a paper by Mani et al. (2018), which looks at the effects of temperature and precipitation changes on living standards in South Asia. The paper has lots of informative, pretty pictures down to the district level, and is very vivid and visual. IPCC documents too are full of these complicated headline graphs, and a lot of time and attention is given to such visuals. So I would encourage the authors also to visualize their data and locate the results in the larger deliberative, policy conversations around climate change in India.

Getting to the GDP headline number, which is the part that attracted me the most, because if we can stand by this figure of a 29 percent per capita loss, it really cracks open the conversation. However, there are a couple of things that I would worry about. One of these is the damage functions, and though Kevin talked us through the complexities, some people think they are a bit dodgy. It is hard to figure out whether the paper has drawn those curves right, especially if they are for a country rather than for the world. But I think the authors are right: and they are well within the bounds of the literature.

The part that I am more worried about is the use of the term "current policy" in the discussion of their quantitative results and their chart on consumption losses. I think the paper may do itself a disservice and border on the sensational by putting out the 6° warming number, which I think is drawn from the RCP 8.5. The Paris pledges that are already on the table and which countries have committed to are estimated to get us to somewhere between 2.7° and 3.3° global warming. So even if we give or take a few degrees, we are still not near 6°. Admittedly, those are pledges, they are not policy yet, but there is a lot of momentum, and many of these pledges are already locked in. So I think at this stage to be talking about 6° warming is probably a little misleading. The numbers shift hugely as Kevin pointed out; 3° warming gives you about a 7 percent loss level and 2° gives about 5 percent. I thought it is actually interesting that when we go from 3° to 2°, which is a huge change and a huge effort in policy terms, you don't see much reduction in GDP losses. I am curious if the authors have an explanation for this.

The other point is about inequality aversion, which is one of the assumptions that the authors make. It is a complicated literature. The inequality aversion, as I understand it, is the relative utility a rich person gets as opposed to a poor person from an extra ton of carbon. As the graph that Kevin showed suggests, the numbers vary hugely with the assumption about inequality aversion. So the higher value that they use, I think 2.45 or thereabouts, lowers the GDP per capita loss at 6° to substantially less than the 29 percent, which is a world of difference in capturing policymakers' attention. The plea to the authors, as they revise this paper, is that the headline GDP number is a wonderful thing to aim for and could rescue climate change from the backwaters, but only if the range can be reduced and made more credible, and some of these concerns are taken care of.

So should we buy the conclusions? The key conclusion that I am taking away from the paper is that if even India were to go to zero emissions tomorrow, it would not make much difference. That is an important conclusion that is consistent with the other cited papers. But the forward-looking conclusion here is: India's climate damage justifies what they call creative concessions to richer countries to induce enhanced actions, and these are in India's interests. I have a few problems with this argument. From an Indian point of view, the reality is that such an approach would bring narrative dissonance, since the dominant narrative in India has been about climate justice, and how we did not cause the problem. Even if this were rational from a policy point of view, it is very hard to imagine that we would be able to act on such an advice because of the dissonance with the dominant narrative in India.

Further, I am not sure that this approach would work in rich countries. For rich countries to be interested in this conversation, India's concession would have to be larger than the perceived competitiveness loss from any mitigation action. So this is not really a two-way relationship. It is a relationship that is driven, at least in the politics of it, by perceived issues around competitiveness. I do accept that what has changed in climate politics a little is a decrease in the extent to which people perceive competitiveness to be threatened by mitigation.

The final observation is that rich countries are also almost certainly absolute losers from climate change. But, is what drives a country's policy response its loss relative to others? The argument would be: I am going to lose a bit; India is going to lose more; therefore, I should expect payment from India. So is it an absolute or a relative loss that drives how countries think about compensation for climate action?

For these reasons, I find the conclusion about creative concessions not the most persuasive implication of the empirical material and analysis that the authors have presented. Perhaps there should be an alternative story that focuses more on co-benefits. I think the climate debate has shifted. It is not about international negotiations, except as an ex-post stamp of approval of national actions and a way of amplifying and ratcheting those actions over time. What matters is what drives national politics. And what drives national politics in India on climate change is likely to be the potential, not always guaranteed, for some of these co-benefit actions in areas like air pollution. This argument is worth pushing. Co-benefits are presumably what has driven the renewable energy story: since renewable energy has become cost competitive, it is consistent with India's energy security interests and is being promoted. It is not really a climate-driven story.

Asking India to provide these creative concessions goes well beyond the much lower risk in just playing nicely at the international negotiations on some issues. I do think the narrative has changed in India, but historically we have held back on some things that I think we shouldn't have been holding back on, like more rigorous transparency mechanisms for all countries and seeking a more robust technical expert review process. In the past, we have been very hesitant about legally binding obligations. These are likely to bind the North just as much as, if not more than, India, because India is actually well down the path of things like the renewable energy transition.

So framing the paper and its conclusions around issues related to India's role in spurring collective action might actually be a bit truer to the analysis and messages that the paper very nicely lays out.

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The objective of the paper is to quantify damages from climate change for India and to examine the implications of this for greenhouse gas (GHG) abatement, that is, climate mitigation by India. The problem is that the two issues are pretty much unconnected—reducing GHG emissions by India in itself will do little to reduce the damage it will face due to climate change. The reason is obvious—climate change is a global externality and will not be affected much by abatement by one country alone. It is a global problem that requires global collective action. India, of course, can and should do its fair share by promoting renewables and cutting back on use of fossil fuels, which has co-benefits in reducing local air pollution and reducing dependence on imports (especially oil). But most importantly (as I argue later), India has to focus on policies and measures to adapt to climate change.

Unfortunately, the paper has little to say on co-benefits and even less on adaptation. The bulk of it is devoted to discuss climate damages for India. Health co-benefits are talked about briefly (two pages in the 20-page draft version), and adaptation not at all. To be fair, the paper acknowledges that reducing India's GHG emissions to zero will do little to limit global warming (Figure 5 in the Conference version) and states that "India is highly vulnerable to climate damages and cannot eliminate the problem by reducing its own emissions." But in that case, the impetus for climate mitigation has to come from co-benefits, and adaptation has to be central to climate policy. It would have been nice if these two issues had been discussed in greater detail.

On the structure of the paper, it is trying to say three things. First, a hotter and more humid world is going to be bad for India—no surprise there! Second, there are co-benefits of mitigating GHGs, that is, we will have cleaner air and better health, etc. Third, the paper has a normative discussion on what India should do vis-à-vis climate change. The first point, that is, a hotter and more humid world will be bad for India, is made in two ways. Since these are disjointed, let me call them 1(a) and 1(b), and discuss them separately. 1(a) is merely a review of microeconometric studies that argue that a hotter climate is bad—actually they have this tweak that it is not just hot that matters, it is hot and humid that matters. This according to them is a kind of a new idea (hardly so!). They cite studies that show that in a hotter and more humid world, there will be higher infant mortality. Another point they make from citing existing microeconometric studies is that a hotter and more humid climate will affect labor productivity. These things are well known. No surprises here. All of this is secondary literature, and the paper by Geruso and Spears (2018) discussed in detail is not even for India. If I have understood the paper correctly, there are no regressions or any meta-analysis in the paper, which simply is saying, look, from the microeconometric evidence, this hotter and humid (which is made a big deal of) is going to be bad for India. The results from these are married with projections on what the climate is going to be like. It is only in 1(b) which is totally disjointed from 1(a), where there is new material, namely, results from an integrated assessment model (IAM). There is little else in the paper that is new. In the co-benefits discussion as well, it is basically secondary literature that is cited and that too somewhat perfunctorily.

In 1(b), the paper is taking Nordhaus' RICE model, which is a multi-region IAM in which the world comprises 12 regions, of which India is one. In this model, you are saying, "let us look at the world in two ways." The first is a world with no climate change. Then you are looking at a world where there is climate change, but you are not doing anything about it (business as usual). Obviously, a world with no climate change will have higher welfare as compared to a world where there is climate change and you have business as usual. In IAMs, "welfare" is defined as the sum of discounted utility of aggregate consumption (call it GDP) over time. Since RICE has 12 regions, there are 12 welfare functions/levels, one for each region. The focus here is only on welfare levels for India. The difference between the two levels of welfare (with and without climate change) quantifies climate damage for India. What the paper does is to set this amount equal to the loss in welfare *if there had been no climate change but instead consumption (GDP) had collapsed during 2020–40*. In other words, what the paper is doing is asking, in a world with no climate change, by how much do we have to force consumption down so that we get the same welfare loss as if climate change had happened? This is confusing since in these models, the consumption path is generated endogenously. So presumably the authors have generated a consumption path without climate change and then manually reduced consumption levels for 2020–40 to get the same loss in welfare as in a world without climate change. It's not clear. By the way, the paper's discussion of the social cost of carbon (SCC) in this section is gratuitous. The consumption paths and welfare losses are generated by the model and have little to do with calculating SCC. Also, the paper says not using humidity and only looking at temperature in RICE will understate damages—not really—in a highly aggregate economy wide model. Extrapolating from microeconometric studies on humidity to such a model isn't very meaningful.

But more importantly, the paper is saying, if you don't do anything about climate change, it is going to be a 29 percent drop in per capita consumption/GDP, etc. Why that is an interesting question is because the impact of climate change is going to be much farther out in the future. This is the point that I would have started my comments with. As Navroz said, the paper is trying to quantify the impacts of climate change so that Indian policymakers get scared and do something about it. Unfortunately, that is incredibly naïve because it takes a lot to scare Indian policymakers. I could be saying the same thing about air pollution: that it is very bad, and people are dropping dead, so do something about it. But I don't think it takes us anywhere: Indian policymakers don't get scared, and we live with these issues.

There is nothing in this paper about adaptation, which I find puzzling, because as the paper says, if India were to reduce its emissions to zero, it is not going to make any difference to the global temperature trajectory. But from there, the paper makes the puzzling leap of suggesting that even if it is not going to make any difference, India should mitigate. In doing so, the paper misses out on two opportunities. The first is that this IAM has an adaptation version called AD-DICE, which modifies a DICE model to build in adaptation. I don't see any analysis, particularly for India, being meaningful until we build adaptation into an IAM. The second opportunity the paper has missed is that after talking briefly about co-benefits, that is, reducing GHG emissions will give co-benefits in terms of lower air pollution, this is not reflected in the conclusions, which simply says that India should mitigate.

Let me just cite the way the Conference version of the paper ends. It says

> It would be a moral tragedy if India has to make such a strategic concession to protect Indians from the unjust emissions of rich nations. But climate change involves moral

tragedies. If such strategic concession or other action is required and possible, it would be a mistake for India not to do at least what is in the interest of present and future Indians to protect them from the grave threat posed by unbridled climate change.

Now, if Indian mitigation, bringing our emissions down to zero, is not going to do anything for the global temperature trajectory, then where is this coming from? If it is coming from the co-benefits of mitigation, then that should be formally modeled into the IAM. We simply can't assert that.

So basically what I find in this paper are four disjointed pieces—the first, which is microeconometric evidence, and the second which is an IAM, both of which tell us that climate change will be really bad for India. The third part is that there are co-benefits. And the last part is that India should mitigate.

Let me say a little bit more about adaptation. As India gets richer, there is no reason why it shouldn't adapt. Lee Kuan Yew once said that the greatest invention humankind ever made was the air conditioner. India is a humid country so I don't see any reason why we should ignore such adaptation. The paper cites literature that found that air conditioners moderated the mortality effects of high temperature in 20^{th}-century USA. It is a different matter that the unavailability of data on air conditioner ownership may hinder the testing for this. But I did go through the paper carefully and saw that there really was no discussion of adaptation or any attempt to model it. I would argue on the basis of theoretically rigorous work that India's marginal dollar should be spent on adaptation, and not on mitigation. Perhaps this can be shown through the AD-DICE model. Or it can be shown by building the co-benefits story, so that mitigation would make sense when it is in our own interest in terms of improving local air quality. Otherwise, what we should be doing with the money is climate-proofing agriculture, or doing things on our coast to cope with climate change.

General Discussion

Jeffrey Hammer started the discussion by seeking a clarification on co-benefits. He wanted to know how climate change, or $CO_{2,}$ and the local climate, or PM 2.5, are correlated empirically.

Indira Rajaraman asked if the infant mortality effect figures, which were estimated based on the Geruso and Spears paper, were for India alone or, as it appeared, for all countries in the DHS. Obstetricians do not have a uniform workload across the year and their peak load varies across different parts of the country. Parents are responding endogenously to climate change over the year, avoiding giving birth on hot days that may kill newborn babies. This adaptive response of parents needs to be factored in. Since the authors have data on the month of birth in every place, this could help them assess the extent to which this response varies between wet-bulb incidence areas such as Uttar Pradesh and Bihar and other parts of the country.

Mihir Desai's first question was about the absence of sea level or coastal data in the paper, as sea-level consequences would differ by country, and would thus have different consequences about where populations reside. The second question was about migration, and why relocation was not being subsidized to deal with the localized effects of climate change, especially in states such as Uttar Pradesh and Bihar. In such cases, migration could be the most obvious response.

Devesh Kapur noted that the paper suggested that India could perhaps make some concessions on other non-climate issues to prompt rich countries to do more on climate change. However, he wondered if India should do the opposite, that is, threaten damage to rich countries on issues they care about, by, for example, walking away from the CFC Treaty. CFCs affect ozone and have an inimical impact on temperate-zone countries. If India walks out of that treaty, it would signal that it would negotiate on ozone only when the others are ready to negotiate on climate change. He asked why India should not adopt a more hard-line strategy on other issues rather than the soft strategy being advocated in the paper.

Rajnish Mehra noted, first, that most of the damage assessment functions are level effects. The implications would be different if they were measuring growth rate effects. He mentioned one of his papers on asset pricing implications of macroeconomic interventions where the growth path of the economy changes. If this happens with climate change as well, in those cases one cannot use standard valuation measures like net present value used by damage assessment studies like the RICE and DICE models because they are looking only at level effects. Second, during the Club of Rome debates, many argued that the world was coming to an end because of population growth. But it did not end, because there is a powerful adjustment mechanism in economics called relative prices, and technologies also evolve. He remarked that it was difficult to determine today what would work—spending money to abate emission today or putting money into R&D to abate emission ten years down the road. However, what was certain is that land prices will change everywhere, in Siberia and in Canada, and migrations will take place because different prices are prevalent in different parts of the world. This adjustment mechanism needs to be addressed in the paper.

Shreekant Gupta advised the authors to use the Ramsey Rule when doing simulations with those parameters, which would enable them to arrive at appropriate values for ρ and η.

Agreeing with Gupta, Rajnish Mehra said that including changes in growth rates would change gross output, Y_t^G , in the model, which, in turn, would make a huge difference in level changes.

Avinash Dixit thanked the authors and the audience for a stimulating discussion of the paper.

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