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The Poverty Impacts of Climate Change

A Review of the Evidence

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Abstract

Climate change is believed to represent a serious challenge to poverty reduction efforts around the globe. This paper conducts an up-to-date review of three main strands of the literature analyzing the poverty impacts of climate change : (i) economy-wide growth models incorporating climate change impacts to work out consistent scenarios for how climate change might affect the path of poverty over the next decades; (ii) studies focusing on the poverty impacts of climate change in the agricultural sector; and (iii) studies exploring how past climate variability impacts poverty. The analysis finds that the majority of the estimates of the poverty impacts tend to ignore the effect of aggregate economic growth on poverty and household welfare. The empirical evidence available to date suggests that climate change will slow the pace of global poverty reduction, but the expected poverty impact will be relatively modest and far from reversing the major decline in poverty that is expected to occur over the next 40 years as a result of continued economic growth. The studies focusing on the sector-specific channels of impacts of climate change suggest that the estimated impacts of climate change on agricultural yields are generally a poor predictor of the poverty impacts of climate change at the national level due to heterogeneity in the ability of households to adapt. It also appears that the impacts of climate change are generally regressive, that is, they fall more heavily on the poor than the rich

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THE POVERTY IMPACTS OF CLIMATE CHANGE: A REVIEW OF THE EVIDENCE[1]

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1. INTRODUCTION

The continued decline in global poverty during the last 100 years is a remarkable achievement, a decline that has been even more significant in the last three decades. In 1981, the percentage of the world population living below $1.25 a day was 52 percent. By 2005, that rate had more than halved to 25 percent (Chen and Ravallion, 2010). This trend is expected to continue especially if developing countries manage to sustain the rapid per capita income growth rates they achieved over the last decade. If developing countries do maintain their income growth rates, poverty headcounts at the $1 or $2 per day could turn out to be almost obsolete as measures of well-being over the next 50 to 100 years.

At the same time another process has been unfolding over the last century. Scientific evidence shows that the global mean surface temperature of the earth has been rapidly rising due to increased emission of green house gases (IPCC 2007a). The resulting climate change[2] is likely to have a negative effect on agricultural productivity, particularly in the tropical regions, and to directly impact on poor people's livelihood assets -including their health, access to water and natural resources, homes and infrastructure (World Bank 2010a). There are increasing concerns that the change in the patterns of climatic variability is also likely to add to the already high vulnerability of poor households, which would exacerbate the incidence, severity and persistence of poverty in developing countries. These concerns are rooted in the fact that most developing countries are more dependent on agriculture and other climate-sensitive natural resources for income and well-being, and that they also lack sufficient financial and technical capacities to manage increasing climate risk. In this context, climate change is believed to represent a serious challenge to poverty reduction efforts around the globe.

Given the complexities involved in an analysis of the poverty impacts of climate change, different approaches may be helpful in considering these impacts. One way is to use economy-wide growth models incorporating climate change impacts to work out consistent scenarios for how climate change might affect the path of poverty over the next decades. Another approach is to learn about sector-specific channels through which longer-term climate change affects

[2] According to the Intergovernmental Panel on Climate Change (IPCC) climate refers to the statistical description in terms of the mean and variability of quantities such as temperature and precipitation over a period of time ranging from months to thousands of years. The norm is 30 years as defined by the World Meteorological Organization (WMO). Climate is different from weather which refers to atmospheric conditions in a given place at a specific time. In general, the studies described in this paper deal with the two different components of climate change.

poverty, the size of such impacts, the potential heterogeneity of impacts, and the types of policies that may alleviate the adverse impacts. The information generated by this approach is useful in tackling poverty today, as well as in preparing for how to adapt to climate change in the future. Yet another approach is to explore how current climate variability affects poverty, and then examine the impacts of increased variability on future poverty.

In this paper we review the various studies that have appeared recently with estimates of the poverty and distributional impacts of climate change in these complementary directions. Given the multidimensional nature of welfare and the myriad of ways in which climate change can impact on the different dimensions of household well-being, we limit our discussion to monetary measures (i.e. consumption and/or income per capita) especially since these are used to calculate poverty rates. However, it is important to bear in mind, that climate change may also have serious effects on health which is also an important dimension of welfare, as well as on ecosystem services (apart from agriculture) which are difficult to assign a monetary value. In Section 2 we analyze the potential effects of climate change on poverty from an aggregate perspective without considering any potential heterogeneity of impacts across the population. (The Appendix in the end of the paper contains a detailed description of the methodology and the data used to project the impacts of climate change on poverty using the RICE model developed by Nordhaus (2010)). In Section 3 we describe papers that analyze the channels through which climate change will affect specific sectors of the population based on household level data. Finally, key messages from this emerging literature and policy recommendations are laid out in Section 4.

2. Climate Change and Global Poverty from an Aggregate Perspective

Before reviewing the empirical literature it is worth asking what is involved in making predictions about the poverty impacts of climate change using aggregate data. In general, such predictions require five pieces of information. To begin with, one needs estimates of two elasticities: (i) the *output-climate elasticity*; and (ii) the *poverty-output elasticity.* The output-climate elasticity provides an estimate of the percentage change in output due a change in climate based on historical data and it is useful for predicting the effect of future climate change on economic activity. The poverty-output (or poverty-growth elasticity), also based on historical data, translates percentage changes in output per capita into changes in the poverty rate. In addition to these elasticities, one need to know how climate will change in the future, what the GPD per capita (or income) trajectory would be in the absence of climate change, and how population will grow. In general, papers in this section differ with respect to how they estimate these elasticities and the type of information they use about future projections.

2.1 Backward looking approach

A number of recent studies have opted for a "backward looking" approach to analyze the effects of climate change on economic activity, and ultimately on poverty. These studies, mimicking the approach emphasized in the growth and development literatures, examine the relationship between climate and aggregate economic variables in cross-sections of countries or regions. One advantage offered by this approach is that by examining aggregate outcomes directly, it is possible to avoid relying on *a priori* assumptions about which mechanisms to include in the climate-economy interactions and how these mechanisms might interact, and ultimately influence macroeconomic outcomes. Another advantage derived by the use of cross-sectional data is that they yield estimates of the long-relationship between climate and aggregate output taking into account historical adaptation.

One such study is by Dell et al. (2009) who use cross-sectional data from 134 countries to examine the effects of temperature on the level of GDP. Their output-climate elasticity estimate, based on historical data, reveals that each additional degree Celsius is associated with a statistically significant reduction of 8.9 percentage points of per capita GDP. The authors also provide evidence of this elasticity at the sub-national level by considering the temperature-income relationship using data at the municipal level for twelve countries in the Latin America and Caribbean region. Remarkably, they find a negative relationship between income and temperature when looking within countries, and even when looking within states within countries.[3] However, they make no attempt to either simulate the impacts of the predicted temperature increase on income, or estimate its effect on poverty.

In a similar vein, Andersen and Verner (2010) examine the relationship between temperature and welfare at the municipality level within five countries in Latin America

[3] The within-country cross sectional relationship is substantially weaker than the cross-country correlation, but it remains statistically significant and of an economically important magnitude, with a 1 degree Celsius rise in temperature associated with a 1.2-1.9 percent decline in municipal per capita income (not GDP).

(Bolivia, Mexico, Brazil, Peru, and Chile).[4] The coefficients of temperature (and temperature squared) provide an estimate of the long-run relationship between temperature and welfare (i.e. the output-climate elasticity) inclusive of adaptation. The estimated relationships are then used to simulate the impact of the climate changes that the IPCC projects for the next 50 years. Their poverty analysis is, however, crude. The authors do not attempt to estimate the poverty-output elasticity; they simple assume that a negative relationship exists between per capita income and poverty. As previously explained, income per capita and population growth projections are needed in order to be more precise about the number of poor people fifty years from now. Because of this, the authors are careful to warn that their simulation results should not be interpreted as forecasts but as simply indicative of the direction and magnitude of the effects that might be expected from climate changes. Table 1 below summarizes the estimated impacts of increased temperature on the mean level of welfare along with the *likely direction* of the effects of anticipated future climate change on poverty and income inequality.

A couple of points are worth highlighting. First, the presented estimates (derived from the country specific elasticities and climate projections) refer to the percentage change in per capita income as a result of climate change relative to a world without it. Second, the direction of the poverty impacts due to climate change is derived by assuming a distribution-neutral change in the mean level of welfare. Third, as in the case of per capita income changes, the increase or decrease in poverty refers to a future situation without and with climate change, and not relative to the current situation. Therefore, a prediction that poverty will increase in Brazil does not imply that poverty will be higher relative to the present, but that it will be higher relative to the no-climate change scenario in 2058. Finally, caution should be applied when looking at the reported effects on poverty and inequality since they are based on the distribution of income (per capita) between municipalities and not households.

[4] In four of the five countries the dependent variable in the analysis is income per capita, whereas in Bolivia consumption per capita is used. Four explanatory variables are included in the regression models—temperature, rainfall, education, and urbanization rates.

Table 1 Summarizing the municipality-level analysis

	Effect on average incomes (% change)	Effect on Poverty	Effect on Inequality
Bolivia	2.9	Decrease	Decrease
Brazil	-11.9	Increase	Increase
Chile	-6.7	Increase	Neutral
Mexico	0	Neutral	Neutral
Peru	-2.3	Increase	Neutral

Source: Andersen and Verner (2010)

Assunção and Chein Feres (2009) provide an estimate of the poverty impacts of climate change based on cross-sectional data at the municipality level in Brazil. They first estimate the impact of climate change on agricultural productivity (a proxy for the output-climate elasticity) measured as agricultural output per hectare in each municipality. Next, they use IPCC's temperature and rainfall projections for 2030-2049 to build a different climate vector for each municipality, which is then used to obtain the percent change in agricultural productivity induced by climate change. Their estimates suggest that global warming is expected to decrease the agricultural output per hectare in Brazil by 18 percent, with the municipality-specific estimates ranging from -40 to +15 percent.

The link between agricultural productivity and poverty is explored by means of a cross-sectional regression of the poverty rate at the municipality level against the log of the agricultural output per hectare and the log of the total population in the municipality. Using instrumental variable methods to account for the correlation between agricultural output and the error term of the regression, they estimate that doubling agricultural productivity reduces poverty at the municipality-level by 12.8 percentage points. Based on this estimate they predict that climate change will increase the poverty rate in rural areas by 3.2 percentage points. Considering that the actual poverty rate is 40 percent, the authors claim that the number of poor in Brazilian rural areas will increase by 8 percent. The estimates also reveal interesting geographical variations in the poverty impacts of climate change. While the North region will be the most affected area in absolute terms, with an increase of 6.2 percentage points in the rural poverty rate, the Southern region appears to benefit from a reduction of 0.9 percentage points in the poverty rate.

In order to allow for more adaptation options than those considered by the simple Ricardian approach used in the estimation of the impacts of climate change on agricultural productivity, the authors consider two alternatives. First, they consider a measure of total poverty taking into account all residents in each municipality, i.e. including all urban households. This alternative measure of poverty captures the fact that some individuals might adapt to the new climate conditions changing sectors or occupations. Second, they build a migration-adjusted poverty measure.[5] They then compute a poverty measure using this adjusted sample for each municipality, for both urban and rural areas. After allowing for labor mobility across sectors or across municipalities, the absolute impact in rural areas reduces from 3.2 percentage points, for the case without labor mobility, to 2 percentage points.

In sum, these results suggest that climate change is likely to generate heterogeneous effects within Brazil with poverty increasing in the already poorer Northeast region and decreasing in the already richer Southern region. Moreover, the poverty impacts of climate change are likely to be lower depending on the extent to which households are able to adapt by migrating across municipalities or switching sectors of employment. However, the poverty estimates of the Assunção and Chein Feres (2009) study tend to overstate the impacts of climate change on poverty in Brazil since they do not take into account the potential increase in mean per capita income due to economic growth over the next forty years. In other words, they consider climate change as it would happen tomorrow, predicting the impact of a warming climate on the actual poverty rate and not the prevailing poverty rate by 2050 in a world without such a warming. The proper way to present poverty estimates associated with future climate change is to project both output and population growth and then use the elasticities to predict its impact on poverty.

2.2 *Accounting for Future Growth: Evidence from Integrated Assessment Models*

An Integrated Assessment Model (IAM) is a general equilibrium model that relies on micro-evidence to quantify various socio-economic dimensions of climate change and then aggregate these to produce a net effect on national income. IAMs are utilized extensively in the climate change literature to model climate-economy interactions and form the basis of many

[5] For each municipality, they consider a sample comprised of the non-migrant households and those who out-migrate to other municipalities - migrants from other municipalities are also excluded.

policy recommendations regarding greenhouse gas emissions control. The typical output of an IAM is the future trajectories of key economic variables including GDP per capita with and without climate change, as well as income paths under different policy scenarios.[6]

The earliest estimates of the impact of climate change on poverty that we are aware of are those by Anderson (2006). Anderson estimates the impacts of climate change on poverty for Sub-Saharan Africa and South Asia based on PAGE 2002 (Policy Analysis Greenhouse Effect).[7] The PAGE model provides estimates of output and growth in the future without and with climate change. Under the A2 climate change scenario in which global mean temperature increases by 3.9°C by 2100, the cost of climate change in India and South East Asia, and in Africa and the Middle East is predicted by PAGE 2002 to be around a 2.5 and 1.9 percent loss in GDP, respectively, compared with what could have been achieved in a world without climate change. Anderson converts these output and growth projections into poverty impacts, by using regional poverty-output elasticity estimates, population forecasts, and the two assumptions that (i) average household income grows at 0.8 times the rate of GDP per capita[8] and (ii) the distribution of income remains constant. Based on these projections, the author reports that by 2100 climate change could cause up to an additional 12 million people living on less than $2 a day in South Asia and an additional 24 million people in Sub-Saharan Africa.[9]

While the poverty predictions are based on highly aggregative and simplified model that does not take into account adaptation, the illustrative results suggest that climate change will negatively affect poverty. As the *Stern Review* (Stern 2007) rightly notes, these poverty impacts are likely to be smaller if aggregate growth in these countries and regions proceeds faster than what is assumed by the IPCC A2 SRES scenario (which assumes, among other things, a high population by 2010 (15 billion) and a world GPD growing at 2 percent per year). In fact, recent GDP and population growth trends suggest that the A2 scenario's view has been pessimistic, and hence Anderson's poverty impacts might overestimate the actual impact.

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[6] For a detailed description of IAMs in the context of climate change control see Kelly and Kolstad (1999).

[7] PAGE is an IAM used extensively by the Stern Review (Stern 2007).

[8] It is a common practice to multiply the growth rate in GDP by 0.8 so as to get an approximation of the growth rate in consumption. This adjustment factor, however, is not explicitly documented in any published paper that we are aware of.

[9] The Stern Review reports Anderson's results based on the 95th percentile of the climate change damage distribution. Under these higher damages by 2100 climate change could cause up to an additional 46 million poor people in South Asia and an additional 98 million people in Sub-Saharan Africa.

In order to update Anderson's estimates to more realistic projections we develop three scenarios to model the long-term climate change impacts on poverty using the Regional Integrated Model of Climate and the Economy (RICE) developed by Nordhaus (2010). The first scenario (baseline) simulates a world without climate change. The second (business as usual [BAU]) reflects the impact of current trends in economic growth and greenhouse gas emissions (GHGs) on the climate, and the impact of climate change on the overall economy without any emission abatement policies.[10] The third (optimal abatement) is based on Nordhaus's calculation of an emission abatement path, with full participation by all countries, which maximizes global intertemporal economic welfare.

We translate the implications of these different growth scenarios for poverty using historical estimates of growth-poverty elasticities (see the Appendix for details).[11] Table 2 summarizes the main impacts of climate change on global poverty under these three scenarios. In a no climate change baseline, the model projects an annual global real per capita output growth rate of 2.2 percent up to 2055.[12] This contributes to more than halving the world poverty rate at the $2 a day level to 14.1 percent by 2055. Under the RICE model's BAU scenario with climate damage, world gross domestic product (GDP) in 2055 would be 1.5 percent lower than in the baseline. In the BAU scenario, the estimated number of poor in 2055 would be modestly higher by 10 million, compared to the no climate change scenario, with most of the additional poor located in Africa and South Asia. It is worth stressing that this analysis focuses on the expected or mean value of the probability distribution of damage from climate change. Obviously, looking at lower probability extreme outcomes increases the estimates for GDP losses and poverty. Under the optimal abatement scenario, the extra number of people in poverty due to global warming in 2055 is projected to be only slightly smaller: 9 million. That is

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[10] It is useful to benchmark Nordhaus' business as usual scenario against other IAMs. For example, PAGE estimates that the mean loss in world output in 2100 would be 2.9 percent under its high climate change scenario. The RICE model presumes a somewhat larger 3.3 percent loss in 2105. Differences in inferences from various models depend more on whether one examines mean impacts of uncertain climate change or the tails of the impact distribution.

[11] Given the limitations in knowledge and large uncertainties surrounding climate change and its impact on economic growth, and the impacts of growth on poverty, this analysis (as well as Anderson's) should be viewed as indicative only of the potential consequences of climate change on global poverty. There are profound uncertainties at every stage in global warming modeling: uncertainties about future output growth; the pace and direction of technological change, particularly for low carbon energy sources; migration patterns; climatic reaction to rising concentrations of GHGs; and about the economic and ecological responses to changing climate and how impacts should be discounted.

[12] Projected annual per capita growth rates by RICE are decreasing over time. The annual world output growth also masks considerable regional disparities; for example, while China and India are expected to grow at a 3.6 annual per capita rate, the European Union will grow at a 1.8 annual rate.

because the effects of abating global emissions of greenhouse gases on aggregate economic damages necessarily accrue more to higher-income countries. Unlike adaptation, emissions mitigation does not specifically target the poor. The major gains in poverty averted by following the optimal abatement strategy would indeed occur on a longer time horizon, by 2100 and beyond.

Table 2. Climate change impacts on world poverty (at the $2 a day level)

	Number of poor (millions)			Headcount poverty rate (%)		
Scenarios	2005	2055	Change	2005	2055	Change
Baseline	2,069.4	1,259.1	(810.3)	32.3	14.1	(18.2)
BAU	2,069.4	1,269.2	(800.2)	32.3	14.2	(18.1)
Difference from baseline	..	10.1	10.1	..	0.12	0.12
Optimal abatement	2,069.4	1,268.5	(800.9)	32.3	14.2	(18.1)
Difference from BAU	..	(0.7)	(0.7)	..	(0.01)	(0.01)

Source: authors own estimates.

Even though aggregate impacts on poverty seem to be modest by mid-century it does not imply that the impacts will be equally distributed among the population. To analyze how climate change will affect specific sectors of the population one needs to use household-level data and explicitly model the channels through which future warming will affect economic activity.

3. Introducing Heterogeneity: Microeconomic Approach

The discussion so far has relied on the evidence emerging from the relationship between climate (temperature and precipitation) and growth or the level of GDP in a cross section or a panel of countries or municipalities within selected countries. While informative, these studies do not shed any light on the channels through which climate change can impact household welfare. For example, climate change may have a negative effect on agricultural productivity and also affect poor people's livelihood through its effects on health, access to water and natural resources, and infrastructure. Considering the complexities involved in modeling some of these channels, the literature has largely focused on the impacts on agricultural output. This section reviews the quantitative estimates of climate change impacts on poverty through its effects on agricultural productivity.

Over the last few years a large literature has attempted to quantify the impacts of climate change on agricultural productivity at the regional as well as at the country level.[13] The general consensus emerging from this literature is that climate change will negatively affect agricultural productivity and yields, and that the impacts will vary across countries as well as within countries. To the extent that yield changes are good predictors of the changes in the welfare level of rural households, and ultimately of the changes in the poverty rates at least in the rural areas, these findings suggest that climate change would have significant effects on poverty rates. Yet, it is quite plausible that the impacts of climate change on agricultural yields may actually be a rather poor predictor of the poverty impacts of climate change. There is a variety of mediating factors that can mitigate the impacts on the level of household welfare, as well as the distribution of these impacts across different households. The list of such factors includes (among others): the extent of autonomous adaptation by households, such as the ability to migrate or switch employment between agricultural and nonagricultural occupations, the extent of policy induced adaptation through prices and explicit government programs, such as providing access to credit and insurance.[14] Also, the distribution of productive endowments (irrigated and non-irrigated land, skilled and unskilled labor), and the dual role of rural households as consumers and producers of food -and whether they are net consumers or producers- will determine how the impacts are distributed among the population. Economic growth, often absent in the discussion of future impacts of a warming world, will have a tremendous ameliorating effect through the decrease of the food expenditure share on total expenditure, and the reduction of the relative weight of agriculture in national GDP (Nordhaus 1993).

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[13] See Cline (2007) for a synthesis of impacts reported in the literature, and Hertel and Rosch (2010) for a review of methodologies.

[14] Autonomous adaptation is typically distinguished from planned adaptation, which refers to policy-based actions that are needed when market failures or other coordination problems hinder relevant collective responses to climate change.

3.1 General Equilibrium Modeling

The study by Hertel et al. (2010) is an effort to analyze the impacts of climate change through a more careful modeling of the channels and the heterogeneity of impacts in the context of economic growth. They use disaggregated data on household economic activity (stratified by their primary source of income) within individual countries (15 developing countries) and a general equilibrium global trade model (Global Trade Analysis Project or GTAP) to explore how changes in agricultural productivity will affect poverty in poor countries. Although the extent of heterogeneity allowed by their model is limited, a key feature of their model is that allows different type of households to be affected differently by the prices of agricultural goods depending on whether they are net producers or net consumers of food.[15]

They use three scenarios of climate change on agricultural productivity (low, medium, or high productivity) to evaluate the resulting changes by 2030 in: (i) global commodity prices, (ii) national economic welfare and (iii) the incidence on the poverty headcount rate (defined as the portion of a nation's population living on less than $1 a day). The poverty consequences of a decline in agricultural productivity are evidenced through two channels: *changes in earnings* and *changes in the real cost of living at the poverty line*. The impact of a food price rise on earnings depends on the income sources for a given household group (these earnings shares are estimated from household survey data). If earnings rise faster than the cost of living for households at the poverty line in a given stratum, then the poverty headcount falls and vice versa. The responsiveness of the stratum poverty headcount to a given real income shock is determined by the density of the stratum population in the neighborhood of the poverty line, and is also estimated from the household survey data. When combined with information about the distribution of national poverty across socio-economic strata, the authors are able to estimate the change in the national poverty headcount.

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[15] The authors consider seven types of households based on their primary sources of earnings (i.e., where they earn 95% of their income): agricultural self-employed (farm income), non-agricultural (non-agricultural self employed earnings), urban labor (urban households with wage labor income), rural labor (rural households with wage labor income), transfer payment dependent, and two groups of households with non-specialized income sources (urban diverse and rural diverse).

A number of interesting findings emerge from this modeling effort. First, large changes in grain prices do not translate into large changes in the cost of living.[16] This is because consumers adjust their consumption bundle to account for the new pattern of prices and staple grains are only one part of the total consumption bundle. To quote the authors: "*while world prices for staple grains rise by an average of more than 30% in the low productivity scenario, the average impact on the real cost of living at the poverty line is more modest –just 6.3%*." Second, the portion of the poverty change driven by the changes in the cost of living (the product of the percentage change in the real cost of living at the poverty line and the stratum-specific elasticity of poverty with respect to real income) are largest for the urban wage labor household stratum. This is because the density around the poverty line in the urban wage labor household stratum is relatively high. In contrast, the agriculture-dependent households show the smallest change.[17] Third, in the "low productivity" scenario (higher temperature), rising world commodity prices translate into increased returns to factors employed in agriculture. Consequently, they report a sharp increase in earnings and a drop in the poverty rate for the agricultural self-employed households. On the other hand, poverty rises for the non-agricultural specialized households, the returns to which fall due to the decline in the *relative price* of non-agriculture commodities, compared to agriculture goods. Under the "high productivity" scenario these results are reversed, with no apparent effect on poverty for the medium climate change scenario. Fourth, the combined poverty impacts on agricultural self-employed households are positively correlated with the size of the productivity shock –with lower global productivity generating higher agricultural prices and reduced poverty amongst these households. The opposite is true of the non-agricultural self-employed households. The net change in national poverty depends on the contribution of each stratum to overall poverty.

In sum, the overall, and by-stratum, poverty changes across all countries for the low-productivity climate change scenario illustrate that nearly all countries have some strata

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[16] Another feature of their model is that all households in each region face the same prices and have the same preferences. Therefore the change in the estimated real cost of living at the poverty line is the same across strata for any given country.

[17] Differences in impact of cost of living changes on poverty for different types of households are a result of differences in poverty elasticities across strata within each country.

where poverty is increased and others where poverty is decreased. The notable exceptions are most African countries where yield impacts of climate change are severe and no single stratum experiences significant poverty reductions.

The study by Hertel et al (2010) provides a promising approach for studying the impacts of climate change taking into account general equilibrium effects between agricultural productivity, cost of living, and earnings effects. However, as is the case for most models, there are serious trade-offs associated between the tractability of the general equilibrium effects and the heterogeneity incorporated into the model.

3.2 Heterogeneity Galore

The study by Jacoby, Rabassa, and Skoufias (2011) applies a flexible framework for quantifying the distributional impacts of climate change in rural economies. In this study welfare is measured by consumption per capita and is modeled as being determined by the resource endowments of the household, such as land and labor, and the returns from farm and non-farm activities.[18] Using a comparative statics framework, the impacts of climate change on household consumption can be expressed as the impact of changes in temperature on the returns to land (used as a summary measure of agricultural productivity) multiplied by the proportion of income derived from owned land, the impacts of temperature on the returns to labor multiplied by the proportion of income derived from labor, and the impacts of climate change on the price of food multiplied by the net consumption ratio, i.e. the value of the net marketed surplus of food by the household.[19]

Using micro data representative for all India and following the Ricardian approach proposed by Mendelsohn et al. (1994) the authors estimate the impacts of climate change in 2040 on agricultural productivity and wages taking into account adaptation (i.e. using district-level cross sectional data) and assuming imperfect mobility of labor.[20] They are also able to estimate

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[18] Additional heterogeneity is introduced into the model by distinguishing between the type of land owned by households (irrigated vs. non-irrigated) and different types of labor (skilled and unskilled). Each of these endowments may have different returns and responses to climate.

[19] It should also be noted, that the impacts of climate change are derived based on the current stock and distribution of endowments of land and labor.

[20] The effect of climate change on the price of cereals in India is obtained from the ENVISAGE (Environmental Impact and Sustainability Applied General Equilibrium), a multi-sector computable general equilibrium model developed at the World Bank for assessing climate change effects and policies. The model predicts that cereal prices will rise approximately 10 percent by 2040 due to warming.

the impacts of climate change on agricultural productivity in the absence of adaptation using panel data at the district level (Deschenes and Greenstone 2007). Combining these estimates of the impacts of climate change on the returns to land and labor with the household specific information on endowments of land and labor, one is able to derive household-specific impacts of the climate change on consumption which is a prerequisite for a proper distributional analysis.[21]

The main results emerging from the study of Jacoby et al. (2011) are as follows: First, the substantial fall in agricultural productivity (17 percent overall inclusive of adaptation) that is predicted as a result of warming will translate into a much more modest consumption decline (of 6 percent on average) for the majority of households. This is because these households derive the bulk of their income from wage employment and (rural) wages are estimated to fall by only a third as much as agricultural productivity. The same general pattern is observed in the case of no adaptation.[22] Second, climate change will have heterogeneous impacts across geographical areas and across the income distribution (see Figure 1). Ignoring cereal price effects, climate change appears "progressive" insofar as wealthier households suffer proportionally greater consumption losses. A household in the top percentile of the per capita expenditure distribution would experience nearly a two percentage point greater decline in consumption than a household in the bottom percentile. This progressivity is driven by the skewed land distribution and the fact that larger landowners are concentrated in the higher percentiles. By contrast, temperature-induced wage declines are relatively more costly to the poor than to the rich, mainly because the poor tend to engage in climate sensitive agricultural employment. Third, once the welfare effects or rising cereal prices are taken into account; climate change impacts are regressive, falling more heavily on the poor than the rich. This is true in urban areas, where it is assumed that cereal price effects are the only welfare consequence of climate change, as well as in rural areas, where the beneficial impact of higher prices to agricultural producers offsets the decline in land productivity.

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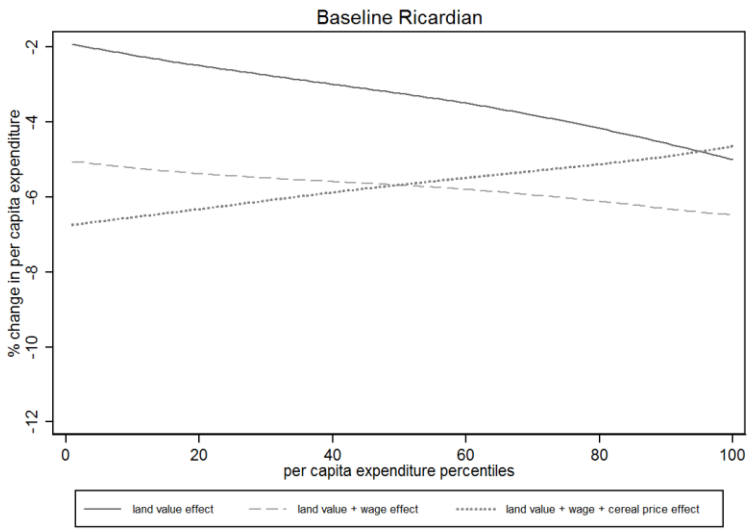
[21] Thus, in contrast to the seven types of households considered in Hertel et al. (2010) in this model there is a continuum of households.

[22] The estimates show that in the absence of adaptation a 1 degree Celsius increase in annual temperature reduces gross productivity per hectare in the range between 24 and 31 percent, which translate into a much smaller decline in consumption between 10.9 and 11.3 percent.

Figure 1 Climate change incidence curves for rural population in India



Source: Jacoby, Rabassa, and Skoufias (2011)

While the model employed by Jacoby, Rabassa, and Skoufias (2011) is primarily equipped for estimating the distributional rather than the poverty impacts of climate change, predictions about poverty impacts can be derived with the help of some additional assumptions. As discussed above, in estimating the poverty impacts of climate change it is important to take into account the growth in the economy over time and the associated decline in the share of food in household consumption. Table 3 underscores the importance of this point by estimating the poverty rates in 2040 assuming different annual growth rates in the level of the average standard of living. Even with a very low growth rate in the level of mean consumption (equal to the average growth rates in mean consumption in India between 1951 and 1990), urban poverty in the presence of climate change is likely to be more than half (at a level of 15.7%) of the poverty rate in urban areas in the base year (32.3%).[23]

[23] It is important to keep in mind that, in India, the mean level of aggregate household expenditure in the National Sample Survey (NSS) accounts for only 60% of the private consumption expenditure from the National Accounts (Ravallion, 2003). Regarding the growth rate in mean consumption in India, it is a common practice to multiply the growth rate in GDP by 0.8 so as to get an approximation of the growth rate in consumption (see footnote 7).

Table 3 Predicted poverty rates with climate change

	Base Year	No Growth	Low Growth	Medium Growth	High Growth
	2004/05	2040	2040	2040	2040
Rural	48.8	54.8	35.8	18.3	2.1
Urban	31.1	32.3	15.7	5.8	0.2
All	44.5	49.4	31	15.3	1.1

Notes: Annual growth rates in mean consumption derived from several NSS rounds are drawn from Datt and Ravallion (2011). Low growth refers to 1958-1991 (0.58 rural and 0.79 urban). Medium growth rates to 1991-2006 (1.17 rural and 1.49 urban). High Growth simply doubles the growth rates under the medium growth rate scenario (i.e. 2.34 rural and 2.98 urban).

Source: Jacoby, Rabassa, and Skoufias (2011)

Taking into account average income growth up to 2040, the national poverty rate will rise by 3.5 percentage points compared to the counterfactual of zero warming (see Table 4). Given the current population projections, climate change is predicted to result in around 50 million more poor people than there otherwise would have been in that year.

Table 4 Differences in poverty rates (in percentage points) due to climate change

	Low Growth	Medium Growth	High Growth
	2040	2040	2040
Rural	5.9	4.4	0.7
Urban	1.1	0.6	0.1
All	4.8	3.5	0.6

Source: Jacoby, Rabassa, and Skoufias (2011)

3.3 The Impacts of Increased Climate Variability on Welfare and Poverty

Although there is a great deal of uncertainty over the exact magnitudes of the global changes in temperature and especially precipitation, it is widely accepted that significant deviations of the variability of climate from its historical patterns are likely to occur (IPCC 2007b). Erratic weather and increased climatic variability will affect agricultural productivity which, depending on how effective was the portfolio of *ex ante* and *ex post* risk management strategies employed by households in urban and rural areas, may translate into reduced income and reduced food availability at the household level.

Numerous studies have examined the impacts of natural disasters and extreme weather-related shocks on different dimensions of welfare (see Baez and Mason 2008, and World Bank 2010b for a thorough review of this literature). In general, they all show that agricultural incomes and, thus, food, basic non-food consumption and investments in human capital, health, nutrition and productive physical assets are likely to be negatively affected by extreme weather events. Many of these studies however, tend to rely on the perceptions of respondents about the incidence of different types of shocks or use data on rainfall and temperature as a tool (e.g. as instrumental variables) to analyze the effect of shocks to income on other outcomes, such as consumption or investments in human capital.[24] Hardly any studies use actual weather data to analyze the general relationship between weather and the level of welfare. A recent study by Skoufias, Vinha, and Conroy (2011) examines whether climatic variability, namely deviations of rainfall and temperature from their long run means, have significant impacts on the average wellbeing of rural households in Mexico. They report that the timing of the rainfall or temperature shock results in a substantial difference in its estimated impact on welfare. For example, per capita expenditures are 14 percent higher if the prior agricultural year (October to September of next calendar year) was at least one standard deviation drier than the average of the last 35 years (1951-1985). However, if the rainfall shock were to be defined within the time frame of the wet season (April to September) then neither positive nor negative rainfall shocks during that wet season appear to have any significant effect on household per capita expenditures.

In a study building on these insights, Skoufias, Essama-Nssah, and Katayama (2011) use data from rural Indonesia and consider two rainfall-related shocks: (i) a delay in the onset of monsoon and (ii) a significant shortfall in the amount of rain in the 90-day post-monsoon period. Focusing on households with family farm businesses, they find that rice farm households located in areas experiencing low rainfall following the onset of the monsoon are negatively affected. A shortfall in the amount of rainfall in the post onset period is associated with a 14 percent reduction in the per capita expenditures of rice farmers. Rice farm households

[24] There is a large literature on the extent to which short-term weather shocks in poor rural areas can have long-term effects on education, health, and nutrition, especially of children. For a recent review of these studies see Baez and Mason (2008).

manage to protect their food expenditures in the face of weather shocks at the expense of nonfood expenditures. The findings regarding the impacts of climatic variability on non-food consumption expenditures are consistent with households reducing their expenditures on health and education. These types of expenditures may ultimately have a longer-term effect on poverty through the reduced investment on the human capital of children.

The study also sheds light on some potential policy instruments that might moderate the welfare impact of climate change. Access to credit and public works projects in communities can help households cope with shocks and thereby play a strong protective role from weather-related shocks. This is an important consideration for the design and implementation of adaptation strategies.

The preceding studies focus on the impacts of weather-related shocks on the mean level of welfare, though not necessarily poverty. The negative effects on welfare suggest that the current risk-coping mechanisms have a limited capacity in protecting welfare from erratic weather patterns. Considering that coping mechanisms are backward looking in the sense that they develop over time based on weather variability observed over very long periods of time, there is a concern about the extent to which they can adjust to the changes in climatic variability predicted over the next 50 to 90 years. All in all, these observations imply that the change in the patterns of climatic variability predicted is likely to reduce the effectiveness of the current coping mechanisms even more and thus increase household vulnerability and poverty further.

Ahmed et al. (2009) is the only study to date making an effort to model the channels and estimate the poverty impacts of extreme weather events such as extreme heat, droughts and floods. They employ the GTAP comparative static computable general equilibrium model. The model, which is practically identical to that in Hertel et al. (2010) discussed above, is applied to 16 countries. The main difference is the origin of the shocks to agriculture, which in this paper is derived from three different sources: (i) the percent of annual total precipitation due to events exceeding the 1961–1990 95th percentile; (ii) the maximum number of consecutive dry days; and (iii) the heat wave duration index.

They analyze 30-year periods from 1971 to 2000 in the 20th century, and 2071 to 2100 in the simulations under the IPCC's A2 scenario.[25] All sixteen countries exhibit substantial increases in the occurrence and magnitude of extreme hot events, with the occurrence of the present 30-year-maximum event increasing more than 2700% in parts of the northern Mediterranean, and the magnitude of the 30-year-maximum event increasing 1000% to more than 2250% in much of central Africa. Most countries also display increases in the occurrence and magnitude of extreme dry events, with peak changes of greater than 800% and 60% (respectively) occurring over Mediterranean Europe.

The magnitude and spatial heterogeneity of changes in climate volatility suggest that the impacts on poverty could also be large and heterogeneous. Among the 16 countries they analyze, those with the highest shares of populations entering poverty due to these extreme events include Bangladesh, Mexico, Mozambique, Malawi, Tanzania, and Zambia. For example, in Malawi and Zambia, simulated grains productivity declines of about 75 percent cause the poverty headcount to increase by about seven percentage points relative to their total populations. There is also tremendous heterogeneity in the poverty vulnerability across different segments of the population (differentiated by primary income source). As in Hertel et al. (2010) the analysis also reveals that the most vulnerable group is the urban wage-labor dependent stratum. While the urban labor group contributes modestly to total poverty in the sample of 16 countries analyzed here, it appears to be highly vulnerable to extreme climate events (e.g. in Malawi, the poverty rate for this group doubles). Zambia and Mexico also show high vulnerability among this group. The source of vulnerability of the urban poor is their extreme exposure to food price increases (with food being a major expenditure, their group's consumption falls with rising prices, pushing them below the poverty threshold of consumption). Agricultural households, on the other hand are much less exposed. While they are generally hurt by the adverse productivity shock as consumers, they tend to benefit from the higher food prices as producers.

Given that the shares of developing countries populations living in rural areas are projected to decrease by more than one third between 2010 and 2050 (United Nations 2009),

[25] As previously discussed, the A2 SRES Scenarios might not truthfully represent the expected GDP and population growth, and the consequential emissions path. As a result, it is an extreme scenario which overestimates the negative impact that climate change will have on poverty reduction efforts.

climate extremes may have greater national-scale poverty impacts in the future because of higher population concentrations in the more sensitive urban strata.

The poverty impacts estimated above are based on simple approximations of how extreme climate events influence poverty by affecting agricultural productivity and raising prices of staple foods. However, it is important to bear in mind that there is an extensive literature that documents that the presence of weather variability (in the absence of credit and insurance markets) is associated with a set of risk management strategies (*ex ante* and *ex-post*) by rural households aimed at protecting household welfare. For example, rural households may undertake *ex-ante* income-smoothing strategies and adopt low return - low risk crop and asset portfolios (Rosenzweig and Binswanger 1993). Households may use their savings (Paxson, 1992), take loans from the formal financial sector to carry them through the difficult times (Udry 1994), sell assets (Deaton 1992), or diversify the portfolio of occupations held by the adult members of the household (Menon 2009). These actions enable households to spread the effects of weather-induced shocks through time. Additional strategies include the management of income risk through ex-post adjustments such as sending children to work instead of school in order to supplement income (Jacoby and Skoufias 1997), adjustments in labor supply such as holding multiple jobs, and engaging in other informal economic activities (Morduch 1995; Kochar 1999). As Elbers, Gunning, and Kinsey (2007) demonstrate, these risk management strategies themselves are associated with increased poverty, and lower investment and growth (i.e. poverty traps). The reason for this is due to the fact that poor households that are credit constrained will choose activities that reduce the variance of their incomes, but that also have lower expected incomes than the activities chosen by wealthier (less constrained) households.

4. KEY MESSAGES AND POLICY CONSIDERATIONS

While the studies surveyed are quite heterogeneous in terms of data (country level vs. household level, and cross sectional vs. panel data), methods (partial equilibrium vs. computable general equilibrium), and focus (regional vs. country-specific), there are a number of messages that can be extracted:

- *Most estimates of the poverty impacts of climate change tend to ignore the effect of aggregate economic growth on poverty and household welfare*. Thus many of the estimates of the poverty impacts provide a very pessimistic, if not unrealistic, scenario. However, it is also important to bear in mind that the extent to which the high growth and the associated large poverty reduction rates of the recent past can be sustained in the future depend critically on whether high growth rates can be maintained by burning less fossil fuels.

- *Climate change will slow the pace of global poverty reduction*, but—based on the mean or expected value of climate damages used in mainstream analyses such as Nordhaus's (2010) RICE model or the Stern Review (Stern 2007)—the expected poverty impact will be relatively modest and far from reversing the major decline in poverty that is expected to occur over the next 40 years as a result of continued economic growth. However, a number of qualifications are in order: First, much of the poverty impact is expected to be concentrated in Africa and South Asia, both of which would see more substantial increases in poverty relative to a baseline without climate change. Second, the occurrence of less probable but more extreme climate damage scenarios would naturally result in larger poverty increases. Third, aggregate projected damages are relatively low over the time horizon analyzed in this note (mid-century). As climate change continues to unfold during this and the next century, aggregate damages could be substantial and have a larger effect on poverty.
- *The estimated impacts of climate change on agricultural yields are generally a poor predictor of the poverty impacts of climate change at the national level*. The evidence from the studies that have been carried out so far and reviewed here suggest that the decline in agricultural productivity resulting from climate change translates in much smaller increases in poverty at the national level. This is primarily due to two factors: (i) *heterogeneity in how climate change* impacts on different geographical areas within countries as well as across the national income distribution; and (ii) *heterogeneity in the ability of households to adapt*, i.e. moving across space and across sector of employment. It is important to keep in mind that the heterogeneity of impacts of climate change across space is not synonymous to heterogeneity in the ability of households to adapt (*ex-ante or ex-post*) to the changes in climate.
- *It also appears that the impacts of climate change are generally regressive, i.e. falling more heavily on the poor than the rich.* The impacts of the higher food prices associated with the global increase in temperatures are likely to have different effects on households who are net producers of food compared to households who are net consumers of food. Net producers

are likely to benefit from higher prices while net consumers are likely to be hurt. Although there is a great deal of uncertainty about whether the global decline in agricultural productivity is likely to translate to large increases in grain prices, there is some evidence that increases in grain prices of the order of 30 percent by 2030 translate into considerable smaller changes in the cost of living for those households close to the poverty line. The increasing urbanization suggests that the number of net consumers of food is likely to increase substantially over the next few decades. This suggests that the gradual global warming, as well as the increased incidence of extreme weather resulting from climate change, is likely to hurt urban wage labor much more than rural labor (self-employed in agriculture).

Fortunately, many of the policies that can be effective at reducing the impacts of climate change on poverty are not different from the strategies of sound development agendas aimed at reducing poverty and promoting economic growth. The most important elements of such policies include: Smoothing the price impacts of regional or country-specific climate shocks through international trade; investing in human capital to increase employment opportunities of the poor, accompanied by policies and incentives that facilitate the migration of the poor to the areas with better economic opportunities; providing credit and developing insurance markets; investing in transportation and communication infrastructure; investing in irrigation and/or improved water management to deal with extreme precipitation events; investing in adaptive agricultural research and in information and extension services; improving governance of common-pool natural resources; and creating well targeted and scalable safety nets systems. . The regressive impacts of climate change alluded to above combined with the emerging evidence that access to social protection and credit programs moderate the welfare impacts of climate change suggest that the establishment of safety net programs and the strengthening of the institutions needed for the implementation and scaling-up of such programs should be a critical component of country-level adaptation strategies. In particular, safety net systems that are counter-cyclical, such as conditional and unconditional cash transfers, workfare programs (e.g., food or cash-for work), and social funds (community-level programs in infrastructure, social services, training, etc.) can have immediate pay-offs since they enable countries to deal with economic crises and other shocks that may not be related to climate change and climatic variability.

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I. Methodology

In order to project the impacts of climate change on poverty it is necessary to estimate: (i) how climate change is going to impact the welfare measure (i.e. per capita GDP, or per capita Private Consumption Expenditure (PCE) from National Account Statistics, or household mean income), and (ii) how these changes in welfare measures translate into poverty numbers.

Focusing on the second relation, a simple and straightforward concept is the poverty-growth elasticity. This relationship is derived from the fact that any poverty measure, such as the headcount ratio, can be expressed (for a given poverty line) as a function of the mean of the distribution and the parameters of the Lorenz curve[26]

$$H = L_p^{-1}\left(\frac{z}{\mu}, \pi\right)$$

where H is the headcount index, z is the poverty line, μ is the mean of the distribution, L is the Lorenz curve for a given distribution, and π is a vector of parameters associated to L. Differentiating the previous equation with respect to time we obtain the dynamic counterpart:

$$\frac{dH}{H} = -\frac{L_{pp}^{-1} z}{L_p^{-1}\mu}\frac{d\mu}{\mu} + \frac{L_{p\pi}^{-1}}{L_p^{-1}} d\pi$$

which shows how changes in poverty relate either to economic growth or to changes in the Lorenz curve. The first term on the RHS, also known as the growth component, can be estimated with a regression of the proportionate changes in poverty on the proportionate changes in the welfare measure, with or without controls (*X*):

$$\frac{dH}{H} = \alpha - \beta\frac{d\mu}{\mu} + X\gamma + \varepsilon$$

[26] For further details see Ferreira (2010).

where β is the poverty-growth elasticity with respect to the mean consumption given by μ.[27] For consistency, we replace the household mean income or consumption by the per capita private consumption component (PCE) in the estimation of the parameter of interest. This empirical decision was made because projections from the RICE model are available only for PCE per capita.

There exist differences between estimating the poverty-growth elasticity based on household mean income or per capita PCE. Figure A1.a shows the proportionate changes in the poverty rate against the rate of growth of average income. The overall poverty-growth elasticity (defined as $2 a day PPP) is -2.02 with a (heteroskedasticity corrected) standard error of 0.82. In contrast, Figure A1.b plots the proportionate changes in the same poverty rate against the growth rate in PCE per capita. Though similar, the estimated elasticity of -1.44 (standard error of 0.60) is not as strong as before.[28] It is important to note that these estimations are based on the same countries and time spells, in order to make both welfare measures comparable across both space and time.[29]

II. The Data

The data requirement for this exercise might be divided into two: historical data and projections. Historical data are needed to compute the poverty-growth elasticity. For this purpose we construct a dataset with the following variables: poverty measure ($2 a day headcount ratio), household mean income or expenditure, and per capita PCE. Our dataset includes 91 countries; 75 of them have at least two surveys from the early 1990's until 2000 (last year available). Table A1 lists the countries and survey dates used in the simulation.

Following Ravallion and Chen (1997), we define a "spell" as the maximum distance between two surveys for one country within the time range defined above. We restrict the sample of countries' poverty measure and mean income (or expenditure) to those years which

[27] This parameter could take any sign and magnitude depending on how the distribution changes with economic growth. In other words, the Lorenz curve is not constant over time (see Ravallion and Chen 1997).

[28] These results are similar to those estimated by Ravallion (2001): a -2.50 growth elasticity of poverty based on consumption versus a -1.96 elasticity based on PCE per capita. However, caution must be taken in this comparison because these elasticities were computed for $1 a day at 1993 purchasing power parity.

[29] The PCE per capita has other measurement problems: survey periods do not match exactly the periods used in National Accounts. At the same time, changes in PCE can arise solely from the non-household sector of the economy Ravallion and Chen (1997), Ravallion (2001) and Ravallion (2003).

were computed over the same measure of living standards and area. In some cases, different sub-periods use different measures for a given country; for instance, surveys may switch from income to consumption or extend the survey sample from urban to country representativeness.[30] Given that we are computing poverty-growth elasticities based on PCE we complete the dataset with the per capita household expenditure PPP in 2005 constant terms. All rates of change are compound annual rates.[31]

In order to maintain consistency we grouped countries according to the RICE's classification. For a same reason we estimate the poverty-growth elasticities based on PCE instead of mean household income: climate change projections from RICE are available only for per capita consumption.

A second dataset includes per capita consumption projections from 2005 until 2055 by 10-year intervals based on the 2010 runs of the RICE model (Nordhaus 2010). From this model we obtain growth rate trajectories for two scenarios under climate change: business as usual (BAU) and optimal abatement. The BAU scenario assumes that no climate-change policies are adopted. In contrast, under the optimal scenario those climate-change policies that maximize global economic welfare are adopted, with full participation by all nations starting in 2010. These two macro projections are net of climate-change damages and abatement costs. In order to make these scenarios comparables we create a baseline scenario without climate change based on RICE 2010.[32] We modify the present investment as a function of the gross present output instead of the present output net of abatement and climate change.[33]

III. Simulation Results

Figure A2 shows how PCE is affected by climate change according to RICE projections. Every scenario presents positive annual growth rates for the rest of the century with a decreasing trend. However, the growth gap widens between the no climate change and the optimal or BAU scenarios. Table A2 presents estimations of poverty-growth elasticities for different countries

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30 Data was obtained from POVCALNET.

31 Annualized differences in logs gave similar results (see Ravallion, 1997).

32 Abatement costs are zero in the baseline scenario.

33 Rice model assume that saving rates remain constant.

and regions.[34] All coefficients are negative meaning that a higher PCE per capita will translate into lower poverty rates. However, some regions respond faster to economic growth than others. For instance, with a 2% annual rate of growth and an initial headcount index of 40%; in a relatively inelastic region such as Africa (with a growth poverty elasticity of -0.45) the headcount index will fall by less than 1% per year (or 0.35 percentage points in the first year). The headcount index will be halved in approximately 78 years. By contrast, in a relatively more elastic region such as Latin America with an elasticity of -1.35 which triples Africa's elasticity, it will take about 26 years to halve the initial poverty rate.

Tables A3 and A4 present poverty projections (measured as the number of people living below $2 a day poverty line) under BAU and optimal scenarios compared to the no climate change scenario for each region/country. In the absence of global warming the world's headcount ratio will fall more than 50 percent during the next fifty years, implying that 1.26 billion people will remain in poverty. Most of these them will be located in India and Africa. In absolute terms, climate change would result in an additional 10 and 9.4 million poor globally by mid-century for the BAU and the optimal scenarios respectively. The poverty impacts of climate change also show regional disparities, with India and Africa being the most affected.

Figure A3 shows the additional number of people in the world living in poverty for the baseline and optimal scenarios in relation to a world without global warming. Both curves are upward sloping throughout the century implying that climate change will have a negative impact on poverty. In particular, under the BAU scenario there will be about 10 million more people living in poverty by 2055 than otherwise would have been under no climate change. The optimal trajectory (based on climate change policies that maximize inter-temporal welfare) shows a higher incidence of poverty in the near future as more resources are diverted towards

[34] The use of poverty-growth elasticities to estimate climate change impacts has some appealing features but it also has several limitations that must be taken into account when interpreting results. Even though other approaches, such as Bhalla (2002) and Hillebrand (2008), take into account distributional changes, we are assuming an unchanging within-country distribution of per capita income over time. In other words, we are not differentiating between growth and redistribution effects on poverty. We adopt this assumption mainly for two reasons. First, most empirical evidence found that the poor on average tend to share proportionately in the gains from economic growth and this outweighed the impact of changes in the distribution (Datt and Ravallion 1992, Ravallion 2001, Dollar and Kraay 2002, Kraay 2006 and Ravallion 2007). Second, there is little scientific basis for predicting long-run distributional changes (Chen and Ravallion 2004). At the same, we are assuming that the relationship between growth and poverty (i.e. the poverty-growth elasticity) for the next fifty years will remain constant. These two assumptions are indeed very restrictive, especially as we project poverty impacts for the distant future.

abatement efforts hence reducing the per capita rate of growth. However, the initial negative impact of abatement on poverty is compensated in the future as the optimal policies reduce future warming.

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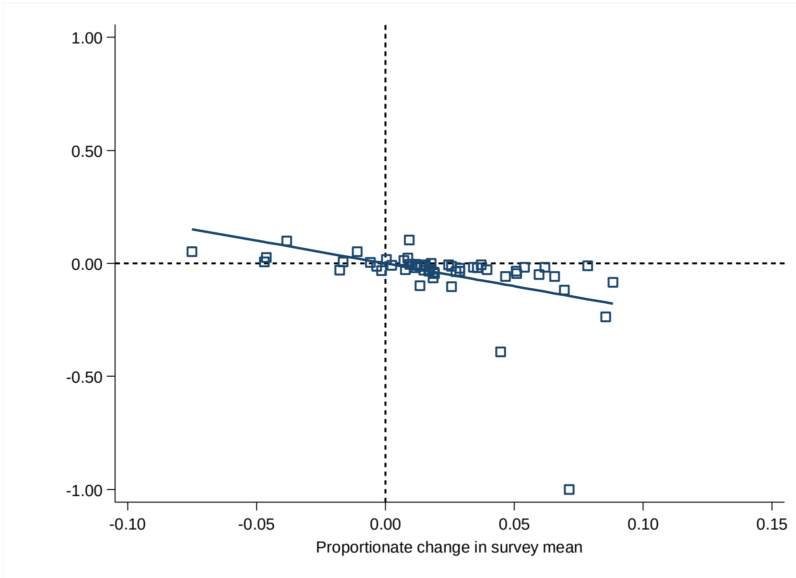
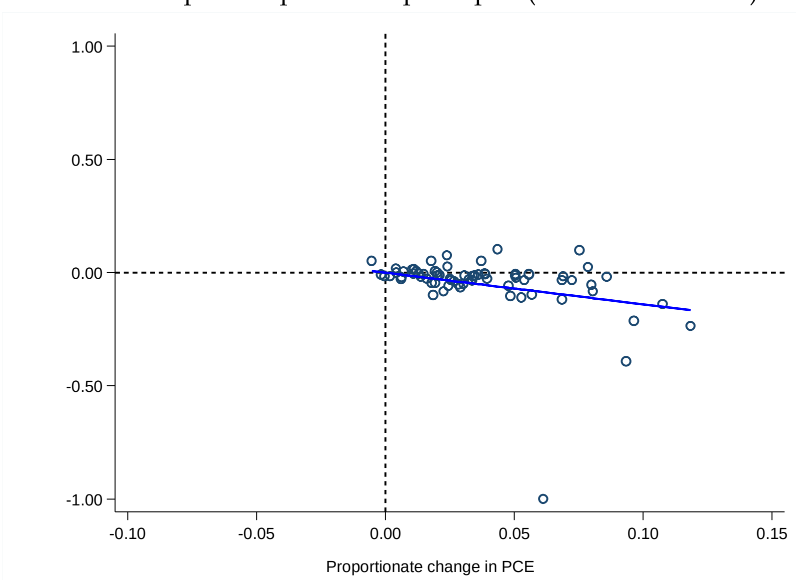
Figure A1: Changes in poverty headcount ratio ($2 a day poverty line)

a. Mean income annual growth rate (from household survey 2005 PPP)



b. Private consumption expenditure per capita (constant 2005 PPP)



Source: Own estimations based on POVCALNET & World Bank (2010)

APPENDIX

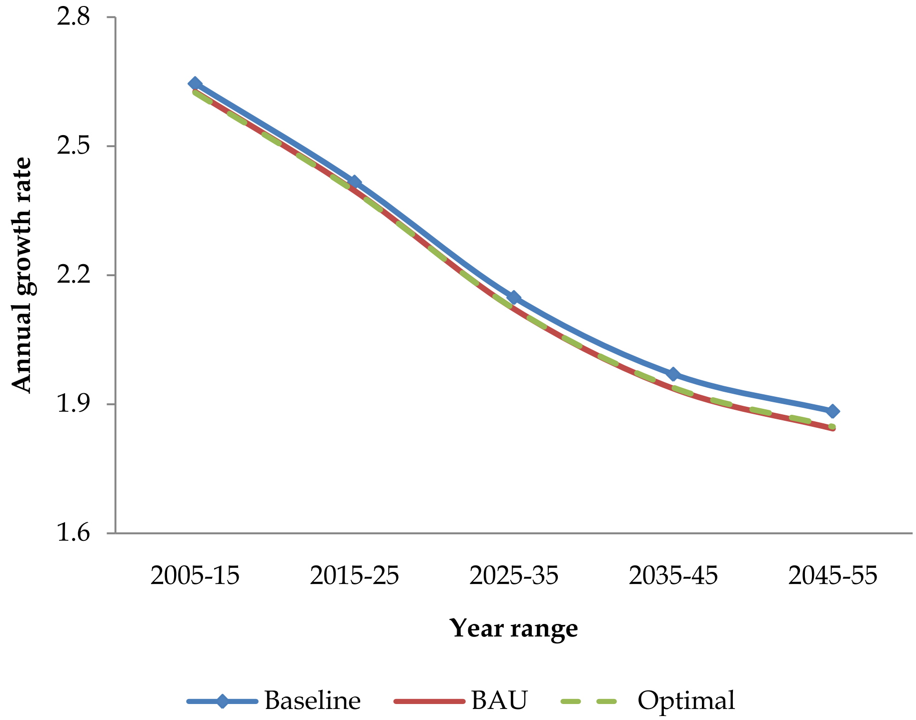
The poverty impacts of climate change using RICE

Table A1: Coverage of the data set

Region	Country	Survey dates		Welfare Indicator	Region	Country	Survey dates		Welfare Indicator
European Union	Czech Republic	1993	1996	Income	Africa	Algeria	1995	n/d	Expenditure
	Hungary	1998	2004	Expenditure		Benin	2003	n/d	Expenditure
	Poland	1992	2005	Expenditure		Botswana	1994	n/d	Expenditure
	Turkey	1994	2006	Expenditure*		Burkina Faso	1994	2003	Expenditure
	Slovak Republic	1996	n/d	Income		Cameroon	1996	2001	Expenditure
						Cape Verde	2001	n/d	Expenditure
Russia	Russian Federation	1993	2007	Expenditure*		Central African Republic	2003	n/d	Expenditure
						Comoros	2004	n/d	Expenditure
EurAsia	Albania	1997	2005	Expenditure		Congo, Rep.	2005	n/d	Expenditure
	Armenia	1996	2007	Expenditure*		Egypt, Arab Rep.	1991	2005	Expenditure
	Azerbaijan	1995	2005	Expenditure		Ethiopia	1995	2005	Expenditure
	Bulgaria	1994	2003	Expenditure		Gabon	2005	n/d	Expenditure
	Bosnia and Herzegovina	2004	2007	Expenditure*		Guinea	1991	2003	Expenditure
	Belarus	2000	2005	Expenditure		Guinea-Bissau	1991	2002	Expenditure
	Estonia	1995	2004	Expenditure		Kenya	1992	2005	Expenditure
	Georgia	1996	2005	Expenditure		Lesotho	1993	2003	Expenditure
	Croatia	1998	2005	Expenditure		Madagascar	1993	2005	Expenditure
	Kazakhstan	1996	2003	Expenditure		Malawi	1998	2004	Expenditure
	Kyrgyz Republic	1993	2004	Expenditure		Mali	1994	2006	Expenditure
	Lithuania	1996	2004	Expenditure		Mauritania	2000	n/d	Expenditure
	Latvia	1998	2007	Expenditure*		Morocco	1991	2007	Expenditure
	Moldova, Rep.	1997	2004	Expenditure		Mozambique	1997	2003	Expenditure
	Macedonia, FYR	1998	2006	Expenditure*		Namibia	1993	n/d	Income
	Romania	1998	2007	Expenditure*		Niger	2005	n/d	Expenditure
	Slovenia	1998	2004	Expenditure		Senegal	1991	2005	Expenditure
	Tajikistan	1999	2004	Expenditure		South Africa	1993	2000	Income
	Ukraine	1996	2008	Expenditure*		Swaziland	1995	2001	Expenditure
						Tanzania	1992	2000	Expenditure
India	India-Urban	1994	2005	Expenditure		Tunisia	1990	2000	Expenditure
	India-Rural	1994	2005	Expenditure		Uganda	1992	2005	Expenditure
						Zambia	1991	2004	Expenditure
Middle East	Iran, Islamic Rep.	1990	2005	Expenditure	Latin America	Argentina-Urban	1996	2006	Income
	Jordan	1992	2006	Expenditure		Belize	1995	n/d	Income
						Bolivia	1991	2007	Income*
China	China-Urban	1990	2005	Expenditure		Brazil	1990	2007	Income
	China-Rural	1990	2005	Expenditure		Chile	1990	2006	Income
						Colombia	1995	2006	Income
Other Asian	Bangladesh	1992	2005	Expenditure		Costa Rica	1990	2007	Income*
	Cambodia	1994	2007	Expenditure*		Dominican Republic*	1992	2006	Income
	Lao PDR	2002	n/d	Expenditure		Ecuador	1994	2007	Income
	Malaysia	1992	2004	Income*		El Salvador	1995	2007	Income*
	Mongolia	2005	n/d	Expenditure		Guatemala	1998	2006	Income
	Pakistan	1991	2005	Expenditure		Honduras	1990	2006	Income
	Philippines	1991	2006	Expenditure		Mexico	1992	2008	Income*
	Thailand	1992	2004	Expenditure		Nicaragua	1993	2005	Income
	Vietnam	1998	2006	Expenditure		Panama	1991	2006	Income
						Paraguay	1990	2007	Income
						Peru	1990	2007	Income
						Trinidad and Tobago	1992	n/d	Income
						Uruguay-Urban	1992	2006	Income
						Venezuela, RB	1993	2006	Income

(*) Head count 2-a-day and PCE from NA available but not household mean income or expenditure
Source: POVCALNET

Figure A2: Annual growth rates of PCE per capita different scenarios (World)



Source: Own estimations based on Nordhaus (2010)

Table A2: Growth Poverty Elasticity – Regions & Countries

	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.Interval]	
Regions						
European Union	-2.523	4.167	-0.610	0.606	-20.454	15.408
Eurasia	-1.863	0.286	-6.510	0.000	-2.473	-1.253
Middle East	-1.060	0.199	-5.320	0.118	-3.593	1.472
Africa	-0.446	0.170	-2.620	0.017	-0.803	-0.090
Latin America	-1.348	0.448	-3.010	0.008	-2.294	-0.403
Other Asian	-1.142	0.166	-6.880	0.000	-1.548	-0.736
Countries						
Russia	-2.078					
China	-1.112	0.620	-1.790	0.324	-8.987	6.763
India	-0.130	0.019	-6.890	0.092	-0.369	0.110

Note: results are weighted based on share of country population over total region population. Estimates were obtained using OLS, regressing the annualized change in the headcount ratio (FGT0) between household surveys on the time elapsed between the surveys and the annualized change in the PCE of National Accounts (constant 2005 PPP). Standard errors corrected for heteroskedasticity and serial correlation.
Source: Own estimations based on POVCALNET and World Bank (2010)

Table A3: Potential impact of climate change on poverty – BAU scenario Number of people living with less than $2 a day poverty line (millions)

	2005	2055		Diff
		Without CC	BAU	
Region				
EU	24.36	0.87	0.93	0.06
Eurasia	26.98	0.24	0.25	0.01
Middle East	67.16	19.80	20.37	0.58
Africa	482.46	342.21	347.94	5.72
Latin America	95.08	7.49	7.67	0.18
Other Asian	70.58	23.78	24.33	0.55
Country				
Russia	2.12	0.03	0.03	0.00
China	473.27	-	-	-
India	827.40	864.72	867.69	2.98
Total	**2,069.40**	**1,259.13**	**1,269.21**	10.08
Headcount rate	32.28	14.11	14.23	0.11

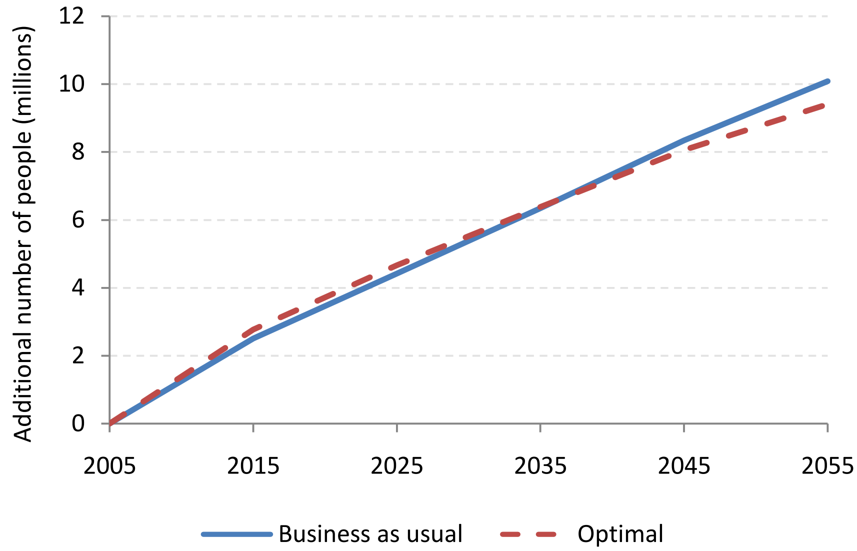
Source: Own estimations based on Nordhaus (2010)

Table A4: Potential impact of climate change on poverty – Optimal scenario Number of people living with less than $2 a-day poverty line (millions)

	2005	2055		Diff
		Without CC	Optimal	
Region				
EU	24.36	0.87	0.92	0.06
Eurasia	26.98	0.24	0.25	0.01
Middle East	67.16	19.80	20.36	0.57
Africa	482.46	342.21	347.45	5.24
Latin America	95.08	7.49	7.66	0.17
Other Asian	70.58	23.78	24.32	0.54
Country				
Russia	2.12	0.03	0.03	0.00
China	473.27	-	-	-
India	827.40	864.72	867.53	2.82
Total	**2,069.40**	**1,259.13**	**1,268.54**	9.40
Headcount rate	32.28	14.11	14.22	0.11

Source: Own estimations based on Nordhaus (2010

Figure A3: Potential impact of climate change on a $2 a-day poverty line (World)



Source: Own estimations based on Nordhaus (2010)