Climate Change, Population Growth, and Population Pressure*

J. Vernon Henderson
Bo Yeon Jang
Adam Storeygard
David N. Weil

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Abstract

We develop a novel method for assessing the effect of constraints imposed by spatially-fixed natural resources on aggregate economic output. We apply it to estimate and compare the projected effects of climate change and population growth over the course of the 21st century, by country and globally. We find that standard population growth projections imply larger reductions in income than even the most extreme widely-adopted climate change scenario (RCP8.5). Climate and population impacts are correlated across countries: climate change and population growth will have their most damaging effects in similar places. Relative to previous work on macro climate impacts, our approach has the advantages of being disciplined by a simple macro growth model that allows for adaptation and of assessing impacts via a large set of climate moments, not just annual average temperature and precipitation. Further, our estimated effects of climate are by construction independent of country-level factors such as institutions.

*Henderson: London School of Economics. Jang: Brown University. Storeygard: Tufts University. Weil: Brown University. We are grateful to Lint Barrage, Eric Galbraith, and Zeina Hasna for helpful advice, and to William Yang and Raymond Yeo for research assistance.

1 Introduction

Climate change over the coming decades will affect the ability of land to support the lives and livelihoods of much of the world's population. In some cases, climate change will literally make land unlivable, for example by putting it underwater. Far more frequently, however, climate change will make land *less* livable or productive. This is most obvious in the case of agricultural productivity, which will be strongly affected by changes in rainfall and temperature. In addition, climate change may lower the quality of life in given regions or require the expenditure of additional resources to maintain a specific quality of life. Beyond reductions in the standard of living, these changes are expected to impact the frequency of conflict as well as flows of population, including migrants and refugees.

Many, though not all, of the economic and social effects of climate change can be understood through the lens of population pressure on fixed local factors of production. The distribution of population in space reflects heterogeneity in these factors: some places are more productive and easier to live in than others, and the places where life and production are easier tend to be where people concentrate. Climate change will alter some of these characteristics, making some locations more attractive and others less so. A decline in the services provided by local fixed factors, what we call the "quality" of land, means that the standard of living will decline or that some of people in a location will be induced to move elsewhere.

In this paper, we introduce a new methodology for projecting the economic impact of forecast changes in climate. Our methodology takes advantage of spatial variation in characteristics that will be altered by climate change in order to estimate weights on different climate components. Notably, we use a large set of climate indicators from global climate models that goes beyond simple annual averages of temperature and precipitation used in most existing research, to include intra-annual variation in both temperature and precipitation, frequency of temperature extremes, and suitability for many specific crops, among other measures. We econometrically assign weights to these multiple dimensions based on their effects on the within-country spatial distribution of population observed today. We pair the results of this econometric exercise with a macroeconomic growth model, which allows us to examine, among other things, the effects of within-country labor mobility.

Our paper makes two contributions. This first is the production of a new set of projections of the economic impact of climate change, at the grid cell, country, and world levels. The general tenor of the projections that we produce is in line with a good deal of previous work, specifically in finding that negative economic effects of climate change will be most severe in poorer and hotter countries, while several colder regions may benefit. But there are significant quantitative differences between our findings and previous research.

The second contribution is to bring together the analysis of climate change and population growth into a single framework, through the lens of population pressure on local resources. Population pressure rises when land quality declines or when population size rises. Our framework allows us both to study the combined impact of these two forces, and to compare their relative magnitudes. Many of the countries expected to suffer degradation in land quality due to climate change are also expected to see large increases in the population that will be reliant on that land, and the increase in population pressure due to having more people to support is on average larger than the increase due to degradation of land quality. Similarly, looking across the range of population and climate projections, uncertainty regarding the effect of population on economic outcomes appears to be bigger than uncertainty regarding the effect of climate.

The rest of this paper is structured as follows. Section 2 briefly reviews the literatures on the effects of both climate change and population growth on economic outcomes. Section 3 discusses our methodology for estimating land quality and how it will be affected by projected climate change. In section 4, we present our estimates of climate effects on land quality at the world, continent, and country levels. Section 5 lays out the economic model that is used to map from changes in climate and population into changes in GDP per capita, and also discusses the role of within-country labor mobility as means of adapting to climate change. Then section 6 presents projected country-level impacts from climate change alone and from climate and population combined. This section also discusses variability across climate and population projections. Section 7 aggregates projected damages from climate change to the world level, to facilitate comparison with other estimates. Section 8 concludes.

2 Previous Literature

2.1 Climate change

Broadly, there are two approaches to estimating the damage function (Hsiang, 2016; Massetti and Mendelsohn, 2018). The first looks cross-sectionally to compare economic outcomes in locations with different climates in the present, and then interacts the estimated effects of climate differences with projected changes in climate in the future. This approach has the advantage of incorporating any adaptations to climate that are present in the current cross section. However, it faces the challenge that cross sectional variation in climate may be correlated with unobserved variables, such as institutions, that impact the economy. For this reason, research in this line tends to use within-country variation as a source of identification. Mendelsohn and Massetti (2017) review a large number of studies that use this approach in the case of agriculture, mostly looking at variation within a single countries. In the work most closely related to ours, Nordhaus (2006) applies it more broadly, regressing total GDP in grid cells covering the whole world on geographical and climate variables as well as country fixed effects. His estimate is that a 3 degree C increase in global mean surface temperature would reduce global output by up to 1.7%.[1] In our estimation of climate damages we differ from Nordhaus (2006) in four dimensions: deploying more spatially disaggregated climate scenarios, considering changes in a broader set of climate attributes, and using population rather than GDP as our dependent variable, and estimating a Poisson rather than long-linear model to relate geographic attributes to economic outcomes.

The alternative approach looks at the relationship between changes in outcomes such as temperature and precipitation, on the one hand, and output or other economic or social outcomes, on the other. The advantage of this approach is that it differences out any unobserved characteristics that may be correlated with climate. The greatest challenge it faces is dealing with adaptation. Hsiang (2016) and Lemoine (2021) discuss the assumptions required to estimate the effects in climate change through variation in weather.[2]

Dell, Jones, and Olken (2012) examine the effects of current and lagged annual average temperature on income growth in a panel data. They find a negative effect of temperature shocks on income growth in poor but not rich countries. They caution that, because their results are for short run fluctuations, they are not necessarily applicable to analyzing the effects of climate change, although they do find similar results in a medium-run analysis that looks at 15 year differences. Burke, Hsiang, and Miguel (2015A) regress annual GDP growth on average annual temperature and its square in a panel of countries over the period 1960-2010. Plugging in projected future temperatures, they calculate income in each country-year relative to a baseline in which warming does not take place. They find dramatic effects. World GDP in 2100 is 23% lower than in the absence of warming. In almost all tropical countries, the projected shortfall is as larger than 80%, and in several (includ-

[1]See also Costinot, Donaldson and Smith (2016), who focus on agriculture.

[2]Waldinger (2022) accounts for long run adaptation in a panel framework by using an historical event, Europe's Little Ice Age of the 16th and 17th centuries.

ing India, Pakistan, and Nigeria) it is larger than 90%. Meanwhile Russia and the Nordic countries all experience gains of over 200%.[3]

A number of papers have compiled damage function estimates from several different sources and estimated an average worldwide damage function from them. For example, the DICE 2016 model (Nordhaus, 2018) embeds a damage function relating lost GDP to the square of the deviation of global average surface temperature from its historical mean. The damage coefficient is derived from fitting this model to 36 existing estimates of damages under different climate change scenarios. The coefficient implies that a rise in mean temperature of 3 degrees C would reduce world GDP by roughly 2.1%, and a 6 degree rise would reduce global income by 8.5%.[4] According to IPCC (2013), the rise in mean surface temperature by the period 2081-2100 is likely to fall into the range of 2.6-4.8 degrees under the RCP 8.5 emissions pathway where there is continuing high use of fossil fuels worldwide. Tol (2019) similarly pulls together 27 estimates of the damage function. For a 6 degree warming, the damage is 5% of welfare equivalent income. However, neither the Tol nor the Nordhaus compilations include the projections from Burke et. al (2015A), which are far larger. Tol and Nordhaus also both discuss the large uncertainty associated with damage function estimates. Krusell and Smith (2022) calibrate their model of the effect of temperature on total factor productivity at the regional level to match the global damage function estimate of Nordhaus.

In addition to the expected effects on GDP, research has also looked at impacts of climate change in many other dimensions. Conflict and migration are particular related in that they are often implicitly or explicitly linked to population pressure. Burke, Hsiang, and Miguel (2015B) and Harari and La Ferrara, (2018) examine the effect of climate on civil conflict. McGuirk and Nunn (2021) show that climate change has already driven increasing con-

[3]Kahn *et al.* (2021) use a similar dataset to estimate autoregressive distributed lag models of the effect of temperature and precipitation deviations from their long run averages on annual income growth. Their central projection is that warming by 2100 under RCP 8.5 would reduce world GDP per capita by 7.2% relative to baseline. Tol (2021) uses a stochastic frontier model that allows for separate effects of weather shocks, on the one hand, and long-run climate change, on the other. These effects are estimated in 65 years of panel data on output per worker at the country level, with climate variation being estimated as the effect of changes in the thirty year averages of temperature and precipitation. He finds that a 3 degree C warming reduces global output by 5%. Most warm weather countries experience reductions in income of 10 to 20%, while many cold and temperate countries benefit. Russia's income rises by 60%. See also Newell, Prest, and Sexton (2021)

[4]A full welfare analysis would include non-market effects, for example species extinction. Nordhaus (2013), as a rough and ready approximation, adds 25% to the loss of GDP from climate change to account for these additional damages.

flict between transhumant pastoralists and sedentary agriculturalists in Africa. Rigaud *et al.* (2018) project that as of 2050, 2.8% of the population in the group of developing countries that they study, or 143 million people, will have had to migrate internally. Similarly Burzyński *et al.* project that 62 million working age adults will have to move, most of them within their own countries, because of climate during the 21st century.[5] A 2021 U.S. government report predicted that over time an increasing fraction of this migration will be across national borders (White House, 2021).

2.2 Population Pressure

The literature studying the economic and social effects of climate change described above is mostly a product of the last several decades. By contrast, literature on the effects of natural resource congestion due to population growth is far older, going back at least to Malthus (1798). Authors such as Hardin (1968), and Ehrlich (1968) focused on the inability of existing natural resources to support ever-growing populations. More recent literature arguing that the resource congestion channel has an important impact on economic outcomes, particularly in poor countries, includes Young (2005), Acemoglu and Johnson (2007), and Kohler (2012). Das Gupta, Bongaarts, and Cleland (2011) point out that discussion of "sustainable development" at the country level is to a large extent simply a reformulation of the Malthusian concern with the ratio of population to resources. Paralleling the more recent literature on climate change and conflict, Acemoglu, Fergusson and Johnson (2020) show that higher growth in population resulted in increases in civil wars and other measures of social conflict. Similarly, pressure on natural resources due to population growth is a hypothesized driver of both internal and international migration.

Although research on this topic does not use the terminology of a damage function, there is no barrier to applying the same concept. For example, the IV estimates in Acemoglu and Johnson (2007) imply that a change in life expectancy that raised population by 1% would lower GDP per capita by 0.79%.[6] Similarly Ashraf, Weil, and Wilde (2013), using a simulation model parameterized to match Nigeria, find that an increase in fertility that raised population by 16.6% would reduce income per capita by 10.6%.[7]

Existing literature does not address the relative magnitude of economic stress due to climate change, on the one hand, and population growth, on the

[5] See also Lustgarten (2020A, 2020B, 2020C).

[6] Tables 8 and 9, column 1.

[7] Values for the year 2060, comparing the UN low and medium fertility projections.

other. To the extent that the two issues are discussed together, it is often in the context of how population affects carbon emissions, and through this channel climate (Casey and Galor, 2017).[8]

3 Projecting Climate Impacts on Land Quality

Our approach follows broadly in the mode of the cross section approach discussed above, most notably Nordhaus (2006). More specifically, we build on the idea of "land quality" introduced in Henderson *et al.* (2022). The key insight is that one can infer the characteristics that affect land quality, and the appropriate weights to apply to them, by looking at current settlement patterns. In order to assess the effects of changes in land quality due to climate change and the effects of population pressure on both resource congestion and growth, we gather information for two periods: roughly current day, encompassing data from 1980 to 2010, and the future, for which we use projections for 2071 to 2100. For convenience, we refer to the former as 2010 and the latter as 2100.

To quantify land quality for 2010, we follow the methodology developed in Henderson *et al.* (2022). Labor, $L_{i,c}$, is assumed to be perfectly mobile within country c across grid cells i each with land area $Z_{i,c}$. Effective, or quality-adjusted, land area $X_{i,c}$ of a grid cell is specified to be quality $Q_{i,c}$ times physical quantity $Z_{i,c}$. Labor moves so that in equilibrium within a country, grid cell density, $L_{i,c}/Z_{i,c}$, is proportional to the quality of the land in the grid cell. Quality in turn is postulated to be a function of the vector of geographic characteristics, $x_{i,c}$, of the grid cell, so $Q_{i,c} = exp(x_{i,c}\beta)$. Thus

$$L_{i,c}/Z_{i,c} = exp(x_{i,c}\beta)C_c, \tag{1}$$

where C_c is a country fixed effect that ensures that we are identifying quality exclusively from variation in population density that is within-country and therefore not driven by national institutions. We estimate (1) globally with Poisson regression.

Estimated land quality for each grid cell is the fitted value from (1), excluding country fixed effects. That is, we define

$$Q_{i,c} = \exp(x_{i,c}\hat{\beta})\Big[\frac{\sum Z_{i,c}}{\sum \exp(x_{i,c}\hat{\beta})Z_{i,c}}\Big]. \tag{2}$$

[8] Vörösmarty *et al.* (2000) discuss the interaction of climate change and population growth in the particular case of demand placed on local freshwater resources.

where $\hat{\beta}$ is the vector of estimated coefficients from equation (1). The term in brackets is a normalization such that the worldwide sum of quality-adjusted area $Q_{i,c}Z_{i,c}$ is equal to the actual area of the world.

Climate change will alter many of the characteristics that determine our measure of land quality. A key innovation in the present paper is to substitute projections of future characteristics into equation (2), allowing us to calculate expected future land quality at the grid cell level:

$$Q_{i,c,2100} = exp(x_{i,c,2100}\hat{\beta})\Big[\frac{\sum Z_{i,c}}{\sum exp(x_{i,c,2010}\hat{\beta})Z_{i,c}}\Big]. \tag{3}$$

In essence, to calculate grid-cell land quality for 2100, we apply the $\hat{\beta}$ coefficients from (1) estimated on 2010 data to future projections of the geographic characteristics. The term in brackets maintains the 2010 normalization from equation (2), so that global average Q in year 2100 is measured relative to 2010.

For the dependent variable in (1), we use the European Union's Global Human Settlements population layer (GHS-POP), which reallocates population estimates from the Gridded Population of the World version 4 (GPWv4) within census units, using data on built surfaces. Geographic characteristics, $x_{i,c}$, include elevation, latitude, ruggedness, distance to the coast, and a set of four dummies indicating the presence of a coast, a navigable river, a major lake, and a natural harbor within 25 km of a cell centroid, all from Henderson *et al.* (2018). From the U.N. Food and Agricultural Organization's Global Agro Ecological Zones v4 dataset (FAO's GAEZ) we add a selection of 33 characteristics that provide information on the thermal regime, moisture regime, and growing period of each grid square for the time period 1981-2010, as well as suitability indices of 11 major crops for the time period 1971-2000.[9] To assess the effect of climate variability, departing from Henderson *et al.* (2022)

[9]The FAO's GAEZ dataset can be accessed at: `https://gaez.fao.org/`. The 33 variables we use comprise the majority of continuous variables from Theme 2: Agro-climatic resources. We exclude variables that overlap in definition, are linearly dependent, assume irrigation, indicate beginning dates, are missing data for a significant area of the world, or have a value of 0 for more than 95 percent of observations. The variables that are dropped under these conditions are: annual temperature amplitude, quarterly P/PET ratios, net primary production with irrigation, beginning date of the longest component length of growing period, the beginning date of the earliest growing period, reference evapotranspiration deficit, snow stock at the end of calendar year, soil moisture condition at the end of the calendar year, and number of days with a maximum temperature of 45 degrees Celsius. We further exclude the number of consecutive days with average precipitation over 45 mm and the average annual sum of precipitation on such days; variation in these two measures is overwhelmingly concentrated in small regions of developing countries. The 11

we include a measure of year-to-year volatility of daily temperature.[10] These data are collected for 237,023 quarter-degree grid squares in 164 countries.

Projections of future climatic conditions are generated by global climate models. These are numerical representations of the earth's climate, in which future states of the world are derived from initial conditions using physical laws. As such, the outputs of these models are highly dependent on the assumed trajectory of carbon emissions from current day to the date of the projection. To ensure that these outputs are comparable, the Intergovernmental Panel on Climate Change (IPCC) has established four scenarios of future greenhouse gas concentrations, called Representative Concentration Pathways (RCPs), as standard inputs for the various models. The four scenarios are RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5, where the number represents the increase in radiative forcing (in watts per square meter) relative to preindustrial conditions by 2100; RCP 2.6 traces the best-case trajectory while RCP 8.5 depicts conditions from sustained aggressive fossil fuel use. GAEZ provides projections for all four scenarios from five different climate models used in the IPCC's fifth assessment report.[11] Our main results rely on the grid-cell level mean of this five-model climate ensemble.[12] In Appendix A, we compare our predictions for changes in land quality between 2010 and 2100 under the 5 climate models with each other and with the ensemble mean. They are highly correlated with each other and, then, obviously with the mean. The larger deviations occur in countries where climate and hence land quality are

crops (banana, cassava, maize, sweet and white potato, dryland and wetland rice, soybean, sorghum, wheat, and yam) are largest in terms of worldwide calorie production. Henderson *et al.* (2022) uses present-day crop suitability indices assuming "low input," or subsistence-level agriculture, but GAEZ only provides crop suitability index projections assuming "high input", or commercialized agriculture. We use "high input" crop suitability indices for both periods for consistency.

[10]To construct this variable, we calculate the standard deviation of the linearly detrended daily average temperature over a 30-year period for each day in the calendar year. We then take the average of these 365 standard deviation values. Temperature values from 1981 to 2010 were used to calculate the 2010 variable, while projected values from 2071 to 2100 were used for the 2100 variable. This mimics measures of volatility used in environmental science papers such as Chan *et al.* (2020) while avoiding concerns about the difference in seasons between the northern and southern hemispheres. Other aspects of volatility are captured by variables in GAEZ: the number of days above 30, 35 and 40 degrees and below 15, 10 and 0 degrees; Annual temperature amplitude; Longest period of consecutive dry days in temperature growing period; Number of consecutive days with average precipitation over 30 mm; and maximum sum of precipitation on consecutive days when average daily precipitation is over 30 mm.

[11]The climate models available in GAEZ are HadGEM2, GFDL, IPSL, MIROC, NorESM.

[12]Multi-model ensemble means tend to improve accuracy (Frankcombe *et al.*, 2018) and are used to generate headline predictions of climate change for IPCC assessment reports.

expected to improve dramatically, rather than in countries where climate will deteriorate. We focus on the latter group, which includes nearly all poor and middle-income countries.

Our measure of quality is based on a worldwide grid square regression. A potential concern is that the value of specific land characteristics in determining economic outcomes may be a function of the level of a country's development. For example, a reduction in rainfall in an already dry climate could be devastating in a region reliant on smallholder agriculture, but in a richer region that imports its food from elsewhere it would have only a marginal effect. We address this concern in Appendix B, where we estimate equation (1) using a sample of grid squares solely from countries with below-median income. We then compare land quality predictions between this and our baseline. The results are highly correlated among the sample of below median income countries;larger deviations occur for countries where land quality is expected to improve dramatically.

4 Projected Effects of Climate Change on Land Quality

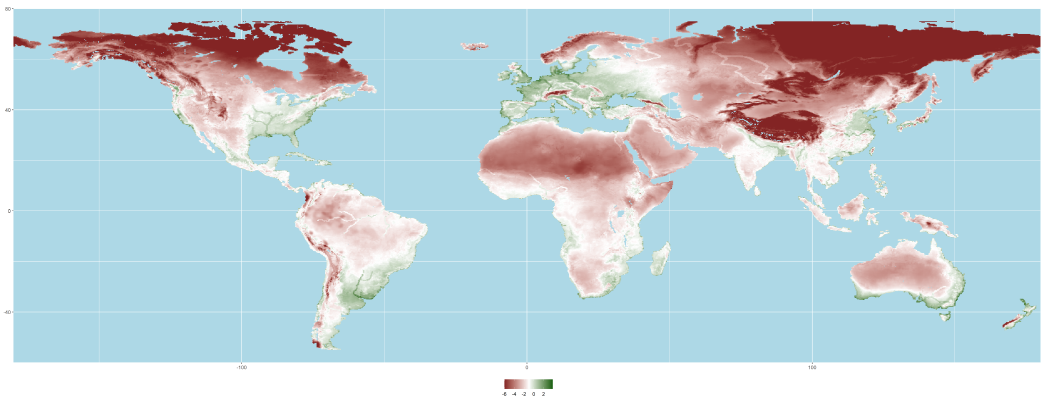
This section begins by reporting the estimated effects of climate change on land quality at the grid square level and then aggregates up to look at world, region, and country impacts on average land quality. Impacts are heterogeneous across the world: Some countries will experience improvements, while many others, especially poorer countries, will see significant deterioration.

4.1 Grid Cell, Global, and Regional Results

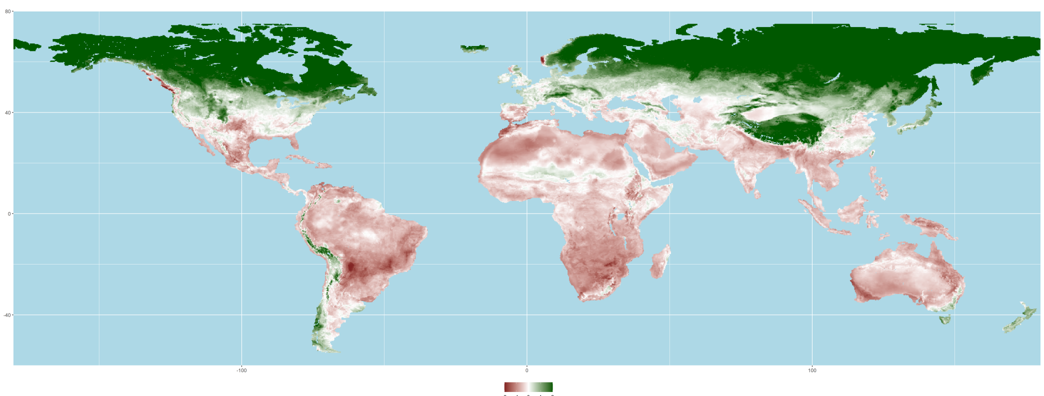
We start at the grid square level. The first panel of Figure 1 shows our estimated values of log 2010 land quality. The second panel then shows projected changes in land quality between 2010 and 2100 under RCP 8.5. In general, the areas with improvements in land quality are mountainous and/or distant from the equator. Land quality declines in almost all of Africa and Australia as well as large parts of South America and central, south, and southeast Asia. The northernmost parts of Europe are projected to benefit, along with most of Canada and Russia. There is a good deal of internal variation within larger countries. For example, within the United States, the Gulf coast suffers declines in land quality while in much of the mountain west it improves.

Figure 1: Log Land Quality

(a) Historical Log Land Quality



(b) Differences between Historical and 2071-2100 Log Land Quality under RCP 8.5



Notes: Data are censored at -6 and 4 and at -2 and 2 in the top and bottom panels, respectively, for visualization. Plate Carrée projection.

To characterize global and regional impacts of climate change more formally, we define (area-weighted) Average Land Quality (ALQ) of region r as,

$$ALQ_{r,t} = \sum_{i \in r} Quality_{i,r,t} \frac{Z_{i,r}}{Z_r} \tag{4}$$

Thus, $ALQ_{r,t}$ is the sum of the quality index in equation (3) for each grid square multiplied by that grid square area, $Z_{i,r}$, all divided by regional land area. A region can be a province, a country, a continent or the world. As we discuss below in section 5, area-weighting ALQ is what matters for income when labor is mobile.

The first column of Table 1, Panel (a) reports world- and continent-level ALQ. As noted above, world average land quality for 2010 is normalized to be one by construction from equation (3). Africa and Asia's ALQ are below the world average while Europe, the Americas, and Oceania's are above it.

In the remaining columns of Table 1, Panel (a), we repeat this exercise for 2100 under the four different RCP emissions scenarios. Here we keep the weights in Equation (3) and simply change the characteristics x according to each RCP scenario. At the world level, the change in average land quality is modest. Under all scenarios ALQ rises; and it rises across scenarios as we move from strong action on climate change mitigation (RCP 2.6) to continued aggressive use of fossil fuels (RCP 8.5). This overall world increase is driven by the rise of average land quality in Europe (including all of Russia), which increases by 32% in RCP 2.6 and 79% in RCP 8.5. There is little average change in the Americas, while there are modest declines in Asia and Oceania. Africa is the big loser, with a decline in average land quality of 14% in RCP 2.6 and 47% in RCP 8.5.

Table 1: World ALQ Change

(a) Area-weighted ALQ

Continent	Historical	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
World	1.000	1.013	1.032	1.043	1.041
Africa	0.705	0.603	0.533	0.498	0.375
Americas	1.149	1.079	1.083	1.082	1.084
Asia	0.741	0.712	0.687	0.670	0.629
Europe	1.320	1.743	1.983	2.110	2.364
Oceania	1.490	1.373	1.365	1.402	1.278

(b) 2010 Population-weighted ALQ

Continent	Historical	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
World	3.022	2.842	2.767	2.753	2.563
Africa	1.642	1.356	1.186	1.100	0.822
Americas	3.814	3.330	3.324	3.274	3.018
Asia	2.541	2.296	2.165	2.121	1.915
Europe	6.375	7.262	7.556	7.822	8.081
Oceania	17.662	15.249	15.982	17.221	14.467

The second panel of Table 1 repeats the analysis using population rather than area weights, replacing the Z's in equation (4) with 2010 populations.

This allows us to look at how climate change will affect land quality experienced in the places where people currently live.

As would be expected, population-weighted ALQ at either the world or continent level in 2010 is far higher than area-weighted ALQ, given that people disproportionately live in higher-quality areas. The effects of climate change are noticeably different from this perspective. Weighted by where people currently live, worldwide average land quality declines by 15% by 2100 under RCP 8.5, rather than increasing as in the first panel. For Europe, the increase in population-weighted ALQ is only 27%, which is only about one-third as large as in the area-weighted case. The other regions see projected declines in ALQ that are larger than in the area-weighted case.

Table 1 shows that taking into account the heterogeneous effects of projected climate change is important. Below we focus on two additional forms of heterogeneity. The first involves the extent to which regions that are projected to suffer declines in land quality are on average poorer than those where land quality is expected to improve. The second concerns the issue that countries with declining land quality are also frequently those with rapidly rising population. The interaction of these two phenomena puts additional strain on the ability of land to support economic activity.

4.2 Country Level Results

Variation across countries is even more striking than variation across continents. We first document this by mapping quality-adjusted area in Figure 2.

As a basis for comparison, in the first panel each country's size is proportional to its land area. [13] The second panel is a cartogram: each country's size now reflects its quality-adjusted area in 2010. Equivalently, the comparison of the first two panels shows current average area-weighted land quality by country: countries that shrink between the first and second panels have lower than average land quality. The most striking differences between the first two panels are in Europe and Africa. Almost all of Europe has land quality that is well above the world average, so these countries are all larger in the second panel than in the first. The opposite is true for most of Africa except its southernmost countries.

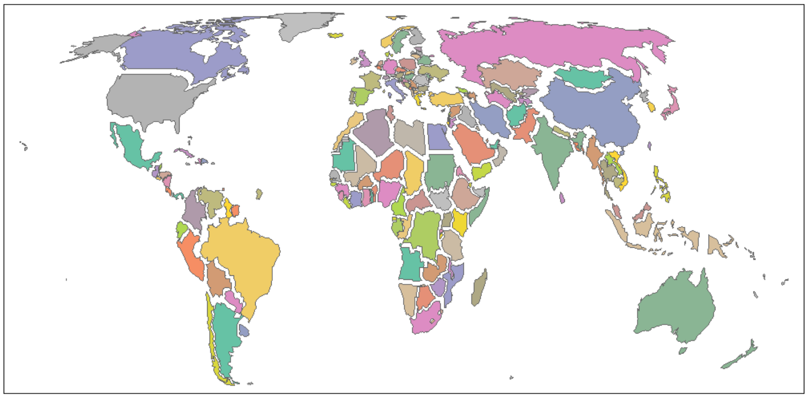
The third panel of the figure reports projected quality-adjusted areas in 2100 under RCP 8.5. Country sizes change between the second two panels in

[13] Note that for visual clarity, each country is shrunk in from its borders by 15% of its area.

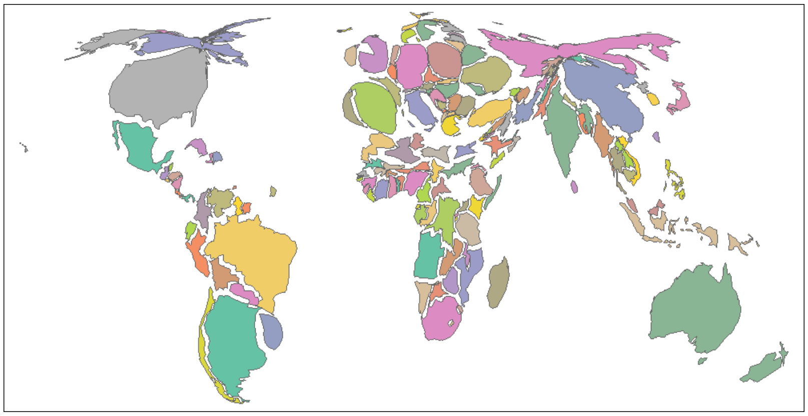
proportion to expected changes in area-weighted ALQ due to climate change. The biggest improvements, not surprisingly, are in northern countries such as Canada and Russia. China also grows. Almost every country in Africa shrinks appreciably, while within Europe there are heterogeneous outcomes, with the northern countries growing and the southern ones shrinking. Individual country values of historical and projected ALQ under all four climate scenarios are provided in the appendix.

Figure 2: Current and Future Quality-Adjusted Area (QAA)

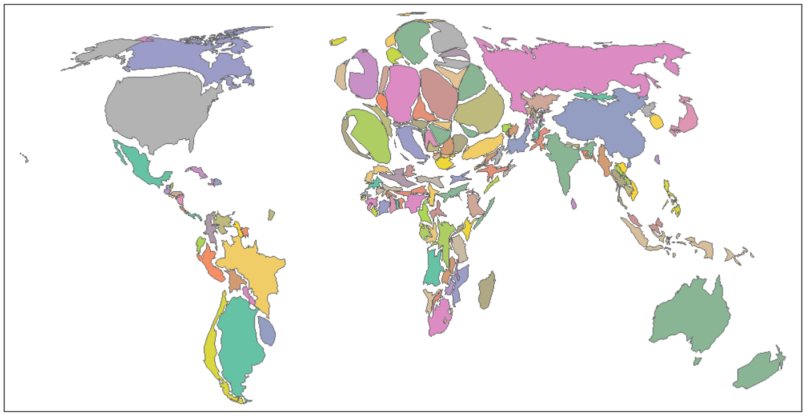
(a) Original Country Size



(b) 2010 QAA



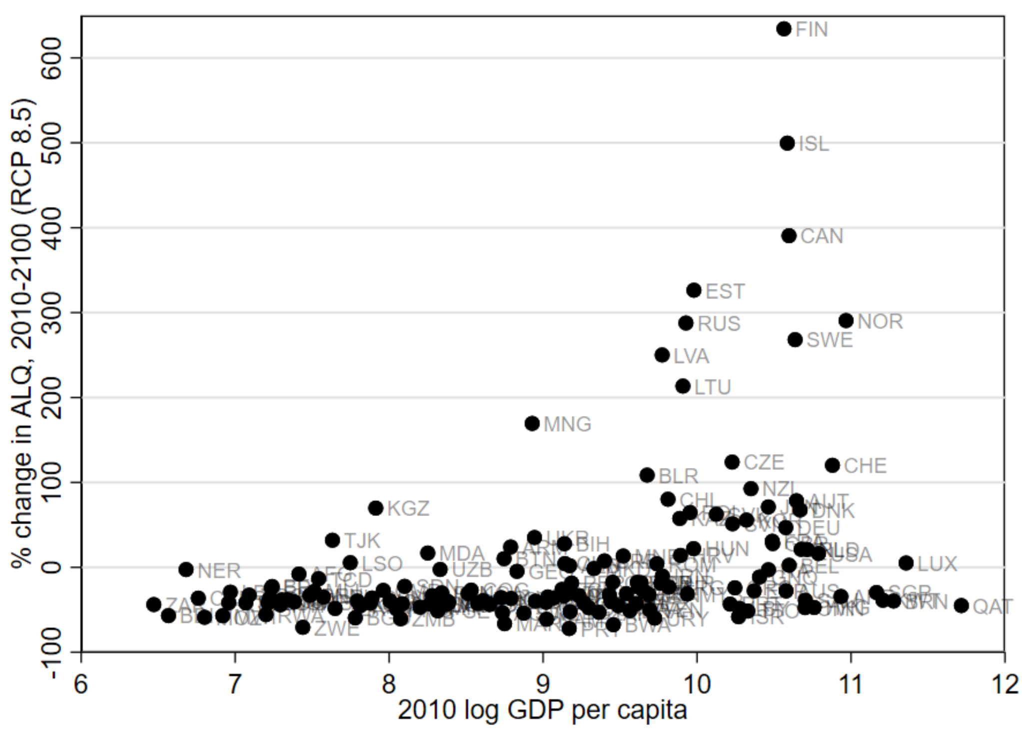
(c) 2071-2100 QAA under RCP 8.5



Notes: Panel (a) is an Eckert IV (equal area) projection. Panels (b) and (c) are cartograms constructed using the rubber sheet distortion algorithm. Area is proportional to QAA for 2010 and for the 2071-2100 period under RCP 8.5, respectively.

Figure 3 shows that there is a strong relationship between countries' current levels of GDP per capita and projected changes in (area-weighted) land quality. Among countries with below-median GDP per capita, the average expected change in area-weighted land quality under RCP 8.5 is -29%; for those in the top half, the expected change is 38%. There is a good deal of variation among the richer countries, with some, such as Israel, Portugal, Greece, and the Gulf states doing poorly, while the Nordic countries, Japan, and New Zealand as well as Russia and Canada all do well. By contrast, among poor countries the projection is almost universally bad, with a few exceptions such as Lesotho, Tajikistan, and Moldova.

Figure 3: 2010 GDP and Future *ALQ* Changes



Note: Figure plots the percentage change in baseline area-weighted ALQ from 2010 to 2100 in RCP 8.5 against log 2010 GDP for the 156 countries with both values.

Taken by itself, this strong relationship between current income and expected effects of climate change on land quality would be a force pushing toward increased inequality among countries. If we instead look at population-weighted land quality, the average expected change remains steady at -30% for countries with below-median GDP per capita, while for the top half the increase in land quality shrinks dramatically to 15%. This suggests that increases to land quality in countries projected to benefit overall are concentrated in sparsely populated cells; internal migration will play a large role in determining whether actual gains are realized from these changes.

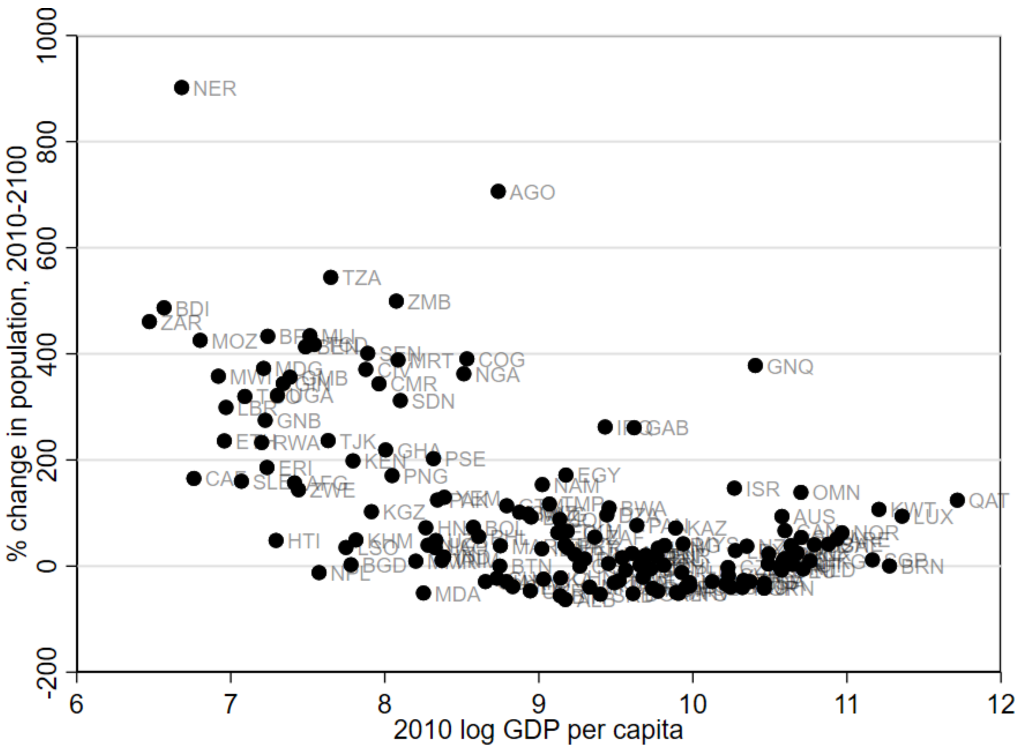
4.3 Population Growth

Declining land quality due to climate change is expected to have economic and social effects because it will mean a decline in the ability of the physical environment to provide support for the people who live in it. A moment's thought suggests that another contributor to this problem is changes in the number of people. To a first approximation, we would expect a decline in land quality by 50%, holding constant the number of people living on it, to have the same economic effect as a doubling of the number of people, holding land quality constant.

Assessing this issue requires projections of future population. Unlike changes in ALQ, these are available only at the level of countries, not grid cells. We use population projections from the by the United Nations Population Division (UNPD, 2019). The UNDP provides a central forecast (the medium variant) as well as a range of probabilistic forecasts for each country. In this section, we use the medium variant projection for the year 2100, while in a later part of the paper we explore the full probabilistic range.

Figure 4 shows the relationship between current GDP per capita and expected population growth between 2010 and 2100 in the UNDP medium projection. The negative relationship is even more pronounced than the positive relationship between current GDP and expected changes in land quality shown in Figure 4. Many wealthy and middle income countries have negative projected population growth, and among the wealthy countries, those that do have positive projected growth generally have projected values of less than half a percent per year. The exceptions are mostly oil producers. By contrast, there are a significant number of poor countries where expected growth over this 90-year period is more than one percent per year, and many with expected growth near 1.5%. We now turn to analyzing the effects on expected economic growth of population pressure on land versus the impact of climate change on land quality.

Figure 4: 2010 GDP and Future Population Growth



Note: Figure plots the percentage change in population from 2010 to 2100 in the U.N. medium variant projection against log 2010 GDP for the 156 countries with both values.

5 Mapping Land Quality Changes and Population Growth into Income: Methodology

Changes in land quality and in the size of the population both act to change the degree of population pressure on natural resources. Following the existing literature on damage functions, our goal is to construct a quantitative measure of how income per capita in countries would differ in 2100 as a result of these changes, from what it would have been in their absence. Although the damage function approach is much more commonly applied in the case of climate change than in the case of population, we show that the two effects can be treated in parallel.

To measure the impacts of climate change and population growth we consider the comparison of specified baseline and alternative scenarios. Let $X_{i,Base}$ and $X_{i,Alt}$ be the 2100 values of quality-adjusted land in grid cell i under these two scenarios, with $L_{i,Base}$ and $L_{i,Alt}$ defined analogously. The choice of what baseline and alternative values to use will depend on the scenario being addressed. All other exogenous factors for each country, such as productivity, are assumed to evolve the same way in the two scenarios.

We analyze a simple growth model. Assume that output in grid cell i is produced with capital (K_i), labor (L_i), and quality-adjusted land, X_i. The production function is

$$Y_i = X_i^{\beta} K_i^{\alpha} (eL_i)^{1-\alpha-\beta}, \tag{5}$$

We suppress the country subscript when there is no ambiguity. e is productivity that is the same throughout a country. We do not explicitly include human capital, but one can think of this as being incorporated into the productivity term.

We need to aggregate from this grid cell production term into a national output equation. To do so, we assume that capital is perfectly mobile, so that the marginal product of capital is equalized across grid cells. It is simple to show that this leads to the capital-output ratio of each grid cell equaling the nationwide capital-output ratio. That is,

$$\frac{K_i}{Y_i} = \frac{K}{Y}, \tag{6}$$

where K and Y are national magnitudes. We use equation (6) to write (5) as

$$Y_i = L_i \left(\frac{X_i}{L_i}\right)^{\beta/(1-\alpha)} \left(\frac{K}{Y}\right)^{\alpha/(1-\alpha)} e^{(1-\alpha-\beta)/(1-\alpha)}. \tag{7}$$

5.1 Labor Mobility

Climate change will have heterogeneous effects within countries. There are many countries where some regions will benefit from climate change while others are damaged; in many other countries, there will be regions that are severely impacted while others are only mildly affected. The extent to which this heterogeneity of climate impacts matters for aggregate output in a country depends on two factors. The first is the degree to which the spatial distribution of population can change in response to climate, which we refer to as labor mobility. The second is the empirical relationship between where population is located in the period prior to climate change, on the one hand, and the spatial distribution of climate impacts, on the other. This second factor is captured in the measure of population-weighted change in ALQ that we presented above.

We consider three cases. In the first ("mobile labor"), labor is perfectly mobile both in the present and the future. The value marginal product of labor is equalized across grid cells in both periods. In this case the distribution of land qualities within a country turns out to be irrelevant, all that matters is a country's total quality-adjusted area. The change in this area is captured by the area-weighted change in ALQ that we constructed above.

The second case is one in which labor is allocated in the present in a way that is not efficient according to our measure of land quality, and this relative allocation of people across grid cells is maintained into the future. The deviation of the current population distribution from the predicted distribution could be due to random errors, unmeasured dimensions of land quality, historical determinants, or agglomeration effects that are not captured in our model. We call this case "immobile labor, historical allocation."

The third case ("immobile labor, initially efficient allocation") is a hybrid of the two just discussed. We assume that population is efficiently allocated in the present, but that relative population across grid cells does not respond to future climate change. Compared to our mobile labor case, this case shuts down adaptation to climate change in the form of internal migration. Thus, comparing the aggregate effects of climate change in these two cases, we can characterize the benefit of internal migration as a form of adaptation. Comparing the second and third cases, we can get insight into the importance of the current distribution of population (relative to the efficient distribution) as a determinant of the impact of climate change. Some countries will turn out to be lucky in the sense that they have an unexpected concentration of population in regions that are expected to do unusually well as a result of climate change, while other countries have bad luck in this respect.

5.2 Mobile Labor

We assume that the wage in each grid cell $w_{i,c}$ includes all income other than returns to capital, so $w_i = (1-\alpha)\left(\frac{Y_i}{L_i}\right)$. Equating worker income across grid cells within a country implies that the labor-land ratio of cell i equals that of cell j and hence that each cell's ratio equals the nationwide labor-land ratio:

$$\frac{L_i}{X_i} = \frac{L}{X}. \tag{8}$$

Substituting equation (8) into (7), grid square output per worker is

$$\frac{Y_i}{L_i} = \frac{Y}{L} = \left(\frac{X}{L}\right)^{\beta/(1-\alpha)} \left(\frac{K}{Y}\right)^{\alpha/(1-\alpha)} e^{(1-\alpha-\beta)/(1-\alpha)}. \tag{9}$$

Through labor and capital mobility, grid-cell level output per capita is a function of national magnitudes and thus is constant across grid cells and equal to national output per capita. We can aggregate labor, quality-adjusted land, and capital to the country-level in each period by simply summing. This corresponds to what we called the area-weighted case in calculating changes in land quality above.

Capital is accumulated in the usual Solow model fashion

$$\dot{K} = sY - \delta K, \tag{10}$$

where δ is the rate of depreciation and the saving rate s is assumed to be fixed. Romer (2012) shows that if the rates of saving, depreciation, population growth, and technological progress are constant, then along the balanced growth path the capital-output ratio, which is the second term in equation (9), converges to a constant. The first term in the equation shows the direct effect of population pressure, via the ratio of people to quality-adjusted land. This is the dominant channel by which changes in both land quality and population affect income per capita. However, both land quality change and population growth also affect the value of the constant capital-output ratio to which the economy converges, for which we now solve for.

Taking logs of (9), differentiating with respect to time, and then rearranging, we can solve for the growth rate of total output:

$$\hat{Y} = \frac{\beta \hat{X} + (1-\alpha-\beta)[\hat{e} + \hat{L}]}{1-\alpha} \tag{11}$$

We can similarly write the equation for the growth rate of capital as

$$\hat{K} = s\left(\frac{Y}{K}\right) - \delta. \tag{12}$$

Equating (12) to (11), the capital-output ratio along the balanced growth path is thus

$$\frac{K}{Y} = \frac{s}{\delta + \frac{\beta \hat{X} + (1-\alpha-\beta)[\hat{e} + \hat{L}]}{1-\alpha}}. \tag{13}$$

This gives us the second term in (9).

Substituting (13) into (9) for the baseline and alternative scenarios,

$$\frac{\left(\frac{Y}{L}\right)_{Alt}}{\left(\frac{Y}{L}\right)_{Base}} = \left(\frac{X_{Alt}}{X_{Base}}\right)^{\frac{\beta}{1-\alpha}} \left(\frac{L_{Alt}}{L_{Base}}\right)^{\frac{-\beta}{1-\alpha}} \times \left[\frac{\delta(1-\alpha) + (1-\alpha-\beta)[\hat{e} + \hat{L}_{Base}]}{\delta(1-\alpha) + (1-\alpha-\beta)[\hat{e} + \hat{L}_{Alt}] + \beta \hat{X}_{Alt}}\right]^{\frac{\alpha}{1-\alpha}}, \tag{14}$$

where the growth rates are annualized differences between the scenario shown and the corresponding 2010 value.[14] In the language of the climate change literature, (14) is one minus the damage function.

Of the three terms on the right hand side of equation (14), the first two have obvious interpretations in terms of population pressure on natural resources: output in the alternative case is lower than in the base case to the extent that land quality in the alternative is lower or that population is higher than in the base. The third term is a more complicated: it shows that to the extent that there is either land quality degradation (i.e. $\hat{X}_{Alt} < \hat{X}_{Base}$) or population growth (i.e. $\hat{L}_{Alt} > \hat{L}_{Base}$) the capital/output ratio in the alternative case will be higher than in the base case. This term provides an offset to the direct effects of land quality change or population growth, although as we will show below, it is quantitatively small.

5.3 Immobile Labor, Historical Allocation

In both this case and the next, we assume migration is impossible. More specifically, we assume that population in each grid cell in a country grows (or shrinks) at the same rate:

$$\frac{L_{i,Alt}}{L_{i,Base}} = \frac{L_{Alt}}{L_{Base}} \tag{15}$$

Aggregate output per worker is given by summing equation (7):

$$\frac{Y}{L} = \left(\frac{K}{Y}\right)^{\alpha/(1-\alpha)} e^{(1-\alpha-\beta)/(1-\alpha)} \sum_i \left(\frac{L_i}{L}\right)\left(\frac{L_i}{X_i}\right)^{-\beta/(1-\alpha)}. \tag{16}$$

Given a balanced growth path, the national capital-output ratio in the first term of equation (16) converges to a constant. As before, we solve for the growth rate of total output on a balanced growth path:

$$\hat{Y} = \frac{1-\alpha-\beta}{1-\alpha}[\hat{e} + \hat{L}] + \frac{\beta}{1-\alpha}\frac{\sum_i \hat{X}_i f_i}{\sum_i f_i} \tag{17}$$

where

$$f_i \equiv L_i \left(\frac{L_i}{X_i}\right)^{-\frac{\beta}{1-\alpha}} \tag{18}$$

[14] This further assumes that growth of population and land quality are both constant on the balanced growth path.

Note that equation (18) is equivalent to the first two terms of equation (7); grid-cell output is proportional to this value. Using equation (12), the capital-output ratio along the balanced growth path can be written as

$$\frac{K}{Y} = \frac{(1-\alpha)s}{(1-\alpha)\delta + (1-\alpha-\beta)[\hat{e}+\hat{L}] + \beta\frac{\sum_i \hat{X}_i f_i}{\sum_i f_i}} \tag{19}$$

Once more, we compare the effects of different scenarios of climate change and population growth against a baseline scenario.

We first define

$$\epsilon_i \equiv \frac{X_{i,alt}}{X_{i,base}}\frac{X_{base}}{X_{alt}}. \tag{20}$$

where $\frac{X_{alt}}{X_{base}}$ indicates the change in quality-adjusted land from climate change for a country as a whole. ϵ_i is cell i's change in quality-adjusted land written as a deviation from its country's overall change.

The analogue of equation (14), which provides the ratio of output per worker in base versus alternative scenarios, under immobile labor is then:

$$\begin{aligned} \frac{\left(\frac{Y}{L}\right)_{Alt}}{\left(\frac{Y}{L}\right)_{Base}} &= \left(\frac{L_{Alt}}{L_{Base}}\right)^{-\frac{\beta}{1-\alpha}}\left(\frac{X_{Alt}}{X_{Base}}\right)^{\frac{\beta}{1-\alpha}}\frac{\sum_i \epsilon_i^{\frac{\beta}{1-\alpha}} f_{i,Base}}{\sum_i f_{i,Base}} \\ &\times \left[\frac{(1-\alpha)\delta + (1-\alpha-\beta)[\hat{e}+\hat{L}_{Base}]}{(1-\alpha)\delta + (1-\alpha-\beta)[\hat{e}+\hat{L}_{Alt}] + \beta\frac{\sum_i \hat{X}_{i,Alt} f_{i,Alt}}{\sum_i f_{i,Alt}}}\right]^{\frac{\alpha}{1-\alpha}} \end{aligned} \tag{21}$$

The first two terms of equation (21) are identical to those in the mobile labor case, equation (13). As before, the last term provides an offset of sorts that we will show does not significantly contribute to cross-country variation in the overall ratio. The third term, which we call the distribution term, is of some interest. If every cell in a region undergoes the same percentage change in land quality, that is, $\epsilon_i = 1 \forall i$, then the distribution term collapses to one, in which case the effect of climate change is the same as in the mobile labor case. If not, the term weights the distribution of land quality changes, ϵ_i, by current output (in equation (7), we see that grid cell-level output is proportional to $f_{i,Base} = L_{i,Base}\frac{X_{i,Base}}{L_{i,Base}}^{\frac{\beta}{1-\alpha}}$). If places with high current activity get favorable changes in land quality, or high activity positively co-varies with ϵ_i, we expect this term to be greater than 1.[15] This is analogous to the population-weighted case in Section 4.

5.4 Immobile Labor, Initially Efficient Allocation

To isolate migration's effect on GDP change, we present a third case in which labor is distributed in 2010 to equalize incomes across grid squares in a country and then proportionally fixed at this initial allocation. The population of each grid cell will grow at the country growth rate. f_i in this case is calculated using the efficient allocation of labor in the historical period $L_i = \frac{L}{X} X_i$, which is then increased by the national growth rate.

Given this, population remains efficiently allocated in the baseline scenario in which there is no effect of climate change on land quality. The distribution becomes inefficient in the alternate scenario with land quality that has been affected by climate change. It then follows from the previous sections that the ratio of output per worker in base versus alternative scenarios becomes:

$$\frac{\left(\frac{Y}{L}\right)_{Alt}}{\left(\frac{Y}{L}\right)_{Base}} = \left(\frac{L_{Alt}}{L_{Base}}\right)^{-\frac{\beta}{1-\alpha}} \left(\frac{X_{Alt}}{X_{Base}}\right)^{\frac{\beta}{1-\alpha}} \sum_i \epsilon_i^{\frac{\beta}{1-\alpha}} \left(\frac{L_{i,Base}}{L_{Base}}\right) \times \left[\frac{(1-\alpha)\delta + (1-\alpha-\beta)[\hat{e} + \hat{L}_{Base}]}{(1-\alpha)\delta + (1-\alpha-\beta)[\hat{e} + \hat{L}_{Alt}] + \beta \frac{\sum \hat{X}_{i,Alt} f_{i,Alt}}{\sum f_{i,Alt}}}\right]^{\frac{\alpha}{1-\alpha}}, \quad (22)$$

Here the third term can be shown to be less than 1 in our context, so that $\frac{(\frac{Y}{L})_{Alt}}{(\frac{Y}{L})_{Base}}$ is less than in (14).[16] Conditional on starting with an efficient allocation, labor mobility can only improve incomes.

[15] The third term of equation (21) subtracted by 1 (the value in equation (14)) may be expressed as

$$\frac{\sum_i [(\epsilon_i^{\frac{\beta}{1-\alpha}} - \overline{\epsilon^{\frac{\beta}{1-\alpha}}})(f_i - \bar{f})] + (\sum_i f_i)(\overline{\epsilon^{\frac{\beta}{1-\alpha}}} - 1)}{\sum f_i}$$

where $\overline{\epsilon^{\frac{\beta}{1-\alpha}}} \equiv \frac{\sum_i \epsilon_i^{\frac{\beta}{1-\alpha}}}{n}$ and $\bar{f} \equiv \frac{\sum_i f_i}{n}$. The second term in the numerator can typically be negative, especially if there are large variations in ϵ_i within a country. This term can partially or fully undo the effect of f_i positively covarying with $\epsilon_i^{\frac{\beta}{1-\alpha}}$. For example, in a 2 region country, if an "overpopulated" region gets an increase in ϵ_i and an underpopulated a decrease, we have the positive covariation. But if the underpopulated region suffers a big reversal in ϵ_i, then overall the third term in (21) will be negative.

[16] The third term can be shown to reduce to $\sum_i \left(\frac{X_{i,Alt}}{X_{Alt}}\right)^{\frac{\beta}{1-\alpha}} \left(\frac{X_{i,Base}}{X_{Base}}\right)^{\frac{1-\alpha-\beta}{1-\alpha}}$.

6 Mapping Land Quality Changes and Population Growth into Income: Results

Equations (14), (21), and (22) provide parallel structures for estimating the effects of projected climate change and population growth under assumptions of perfect labor mobility and no labor mobility. We start with pure climate effects and then compare climate versus population effects on growth outcomes in 2100. For brevity we don't look at effects of different population growth scenarios, absent climate change.

To apply this framework, we need values for the production function parameters. A commonly used estimate for the natural resource share in production, β, is 0.25. While this is probably too high for wealthy countries, we view it as reasonable for poorer countries, which are mostly reliant on local resources. If we assume a one-third share for capital among inputs other than natural resources, we get $\alpha = 0.25$. We further assume that the annual growth rate of productivity, $\hat{e}$, is 1% and depreciation, δ, is 5%. However, these last two parameters are only relevant for the calculation of the offset terms in equations (14), (21), and (22). Appendix Table C5 shows that the offset term contributes extremely little to variation across countries in projected climate impacts, and is very insensitive to the choice of $\hat{e}$.

6.1 Climate Change Effects

To assess the pure effect of climate change, we project outcomes for 2100 under different climate scenarios, allowing for the same expected population growth. For all three equations, we set $X_{i,Base}$ equal to its 2010 value and $X_{i,Alt}$ equal to its 2100 value for each specified climate scenario. We set L_{Base} and L_{Alt} equal to the UN's 2100 median population forecast.[17] Thus we are comparing balanced growth outcomes in 2100 under different climate scenarios holding population growth constant across scenarios.

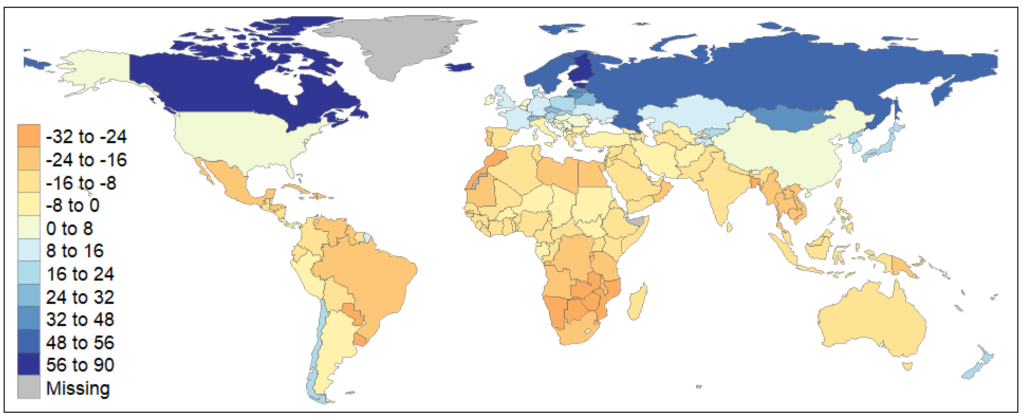
Appendix Table C2 shows country-level impacts calculated using our three different assumptions about labor mobility for all four RCPs. For comparison, the table also shows the RCP 8.5 projections from Burke *et. al* (2015A), which is probably the best known application of the panel-weather approach to estimating the impact of climate.[18] Since the Burke *et al.* results are based

[17]Later, when aggregating to the world level, we will use 2100 populations from the Shared Socioeconomic Pathways to allow for comparisons with previous work.

[18]Country-level projected per capita GDP with and without climate change from Burke, Hsiang, and Miguel (2015A) is provided here.

on population-weighted changes in climate, we compare them to our results under the assumption of immobile labor, historical allocation. The correlation between their projections and ours (expressed in percent changes) is 0.76. However, the magnitudes are very different. In the Burke *et al.* projection, 20 counties suffer damage to GDP per capita of more than 90%, and 72 countries more than 80%. By contrast, our maximum loss is 32%. Similarly, in Burke *et al.* climate change increases GDP per capita in four countries by more than 300%, while in our estimates the biggest increase is 75%.

Figure 5: Country-Level Impacts from Climate Change with Mobile Labor



Notes: Countries are binned by the difference between GDP per capita under RCP 8.5 and no climate change under the assumption of mobile labor.

Figure 5 shows our results graphically for RCP 8.5 under the mobile labor assumption, i.e. equation (14). As expected, Nordic countries, Canada, and Russia gain while countries in or near the tropics typically lose. Among the most extreme projections, GDP per capita is respectively 31.9% and 32.8% below what it would be in the absence of climate change in Zimbabwe and Paraguay, with losses of over 25% in many African countries. On the other end, GDP per capita is 52.6% and 86.6% above baseline in Russia and Finland respectively. These changes accord with the changes we saw in Figures 2b and 2c, where most African countries suffered losses in ALQ while Nordic countries, Russia, and Canada gained.

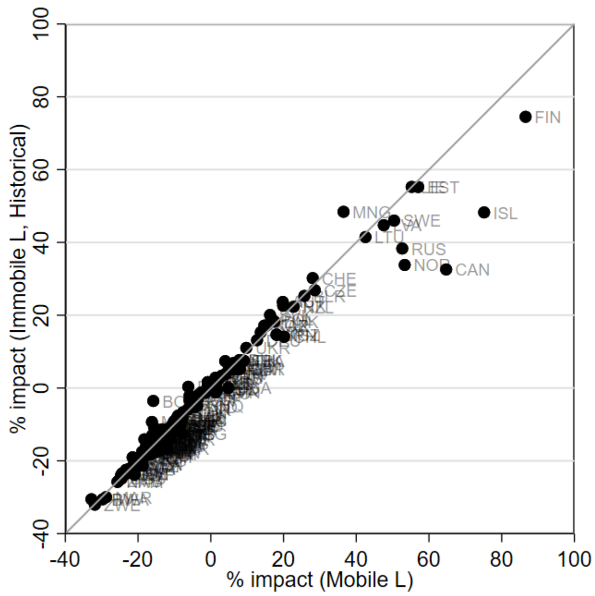
In Figure 6 we compare country level outcomes under the mobile labor assumption to the two other labor mobility assumptions discussed above. Panel (a) compares the mobile labor case to the case of immobile labor, historical allocation, equation (21). It is immediately apparent that, while the two sets of predictions are highly correlated, points are scattered on both sides of the 45 degree line. These deviations from the 45 degree line are result from the unevenness of climate change impacts within a country and the extent to which particularly strong impacts take place in regions that are more or less populated than would be expected based on current land quality. These are the factors captured in the third term of equation (21), which we call the distribution effect. Countries where the distribution term is greater than one are effectively moving toward a more efficient distribution of population, which is to say that climate is improving most where the people already are.

In Appendix Table C3, we provide values for this term in every country. In most, the value of this term is close to 1, implying that either climate change will affect all regions relatively equally, or that the current population distribution is not correlated with variation in climate change impacts. However, in Canada, Iceland, and Norway the third term is well below 1 with values in the range 0.796 to 0.867 because climate changes favor places where few currently live. In contrast, in counties like Peru and Bolivia where for historical reasons many people live in mountainous areas, climate changes favor places where economic activity is clustered and values of the third term are above 1, in this case 1.08 and 1.16 respectively. Another instructive example is Mongolia, where the distribution term has a value of 1.09. The estimated overall increase in GDP per capita for Mongolia is 37% under the mobile labor assumption and 48% under the immobile labor assumption.[19]

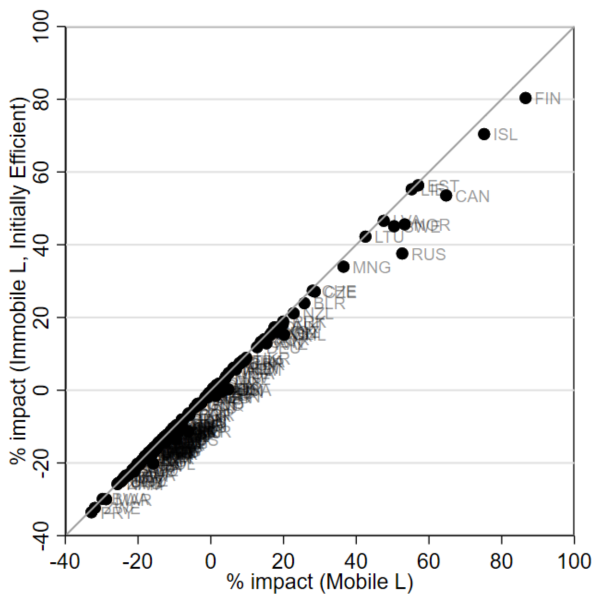
[19]The vertical distance of countries from the 45 degree line in panel (a) of figure 6 is closely related to the difference between the area-weighted and population-weighted change in ALQ discussed above (correlation coefficient of 0.88).

Figure 6: Comparisons of Country-Level Impacts from Climate Change

(a) Immobile Labor, Historical Allocation



(b) Immobile Labor, Initially Efficient Allocation



Note: Figure compares the percentage impact of climate change in 2100 under mobile labor assumptions against that under immobile labor assumptions and an efficient initial allocation of population (panel a) or the historical allocation of population (panel b). RCP 8.5 and the U.N. medium variant population projection are used for each case; 164 countries are depicted in each panel.

To directly see the effect of restrictions to mobility on the impact of climate change, we turn to Panel (b). The horizontal axis again measures the impact of climate change on GDP per capita under the assumption of mobile labor, while the vertical axis measures the same thing under the assumption of immobile labor with an initially efficient allocation. By construction, all countries are now on or under the 45 degree line. The base case distributions of population are the same for the vertical and horizontal measures. For the horizontal measure, population is efficiently distributed in the alternative case (i.e. following climate change), while for the vertical measure it is not. The deviation from the 45 degree line thus measure the cost of labor immobility. As can be seen, these costs are largest for countries far from the equator which are projected to see benefits from climate change. For example, in Russia, GDP per capita would rise by 53% under the mobile labor assumption, but only 38% with immobile labor and the initially efficient allocation.

While the deviations from the 45 degree line in panels (a) and (b) of Figure are interesting objects for study, we think that the most notable message of from this analysis is that for most countries, and certainly for most countries that are expected to suffer negative consequences for climate change, the assumption made regarding labor mobility makes little difference regarding the projected effect of climate change on GDP per capita. For that reason, in what follows we mostly present results for the mobile labor case, although the full set of results for all cases are given in the appendix.

Below, in Section 7, we calculate the world damage function by aggregating these country-level damages of climate change using projections of country-level GDP in 2100.

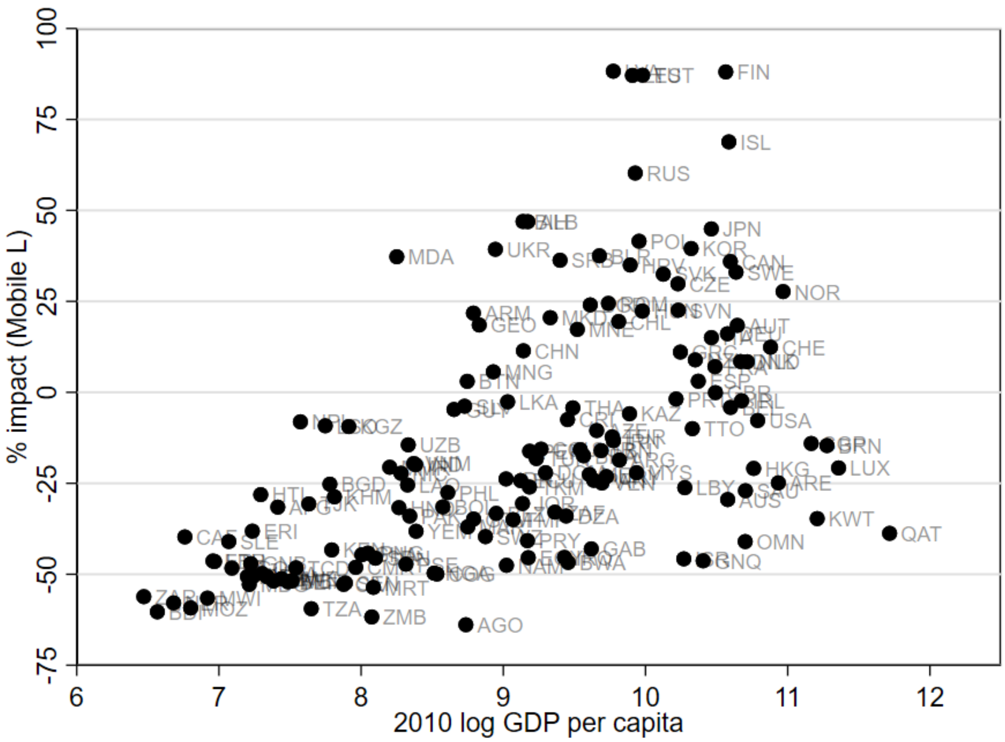
6.2 Combined Impacts from Climate Change and Population Growth

In this section we look at the combined effects of climate change and population growth. In the next one, we then compare their relative magnitudes. Concretely, we will set $X_{i,Base}$ and $L_{i,Base}$ to their 2010 values and then use different combinations of projections to 2100 for $X_{i,Alt}$ and $L_{i,Alt}$. In both sections, we do our analysis only for the case of mobile labor, although results for the other two cases of labor mobility are shown in the appendix. As in Figure 6, the results are highly correlated.

Figure 7 shows the combined impacts from climate change under RCP 8.5 and population growth under the UNDP medium projection, against a base of no population growth and no climate change. In the base, on the balanced growth path, growth is solely based on technological progress.

Because countries that are projected to suffer land degradation from climate change tend to also be the ones where population is growing fastest, the size of impacts in Figure 7 tend to be much larger than those in Figure 5 where population growth does not differ between the base and alternative cases. Many countries, mostly poorer ones, experience losses well over 35% and many even over 50% in GDP under the combined population growth and climate deterioration, while with only climate change the maximum loss was under 33%.

Figure 7: Impacts from Climate Change and Population Growth



Note: The Y axis plots the percentage impact of climate change in 2100 using RCP 8.5 and the U.N. medium variant population projection under mobile labor assumptions. The X axis plots log 2010 GDP. 156 countries are shown.

As in Section 6.1, we see that the northern European countries are projected to have positive impacts on GDP per capita. The impact to Finland, for example, is now projected to be 88.0% due to declines in population compared to 86.6% in the previous exercise. Angola becomes more negative (from -21.5% to -63.9%). Population growth exacerbates the population pressures brought about by climate change. Because land quality degradation from climate change often coincides with higher population growth in developing countries, there is a strong positive relationship between current GDP per capita and the combined impacts from climate change and population growth. The positive correlation between impacts of climate change alone and the log of current GDP per capita in Section 6.1 is 0.41. Here, the combined impacts on GDP of population growth and climate change, are more correlated with the log of GDP per capita, at 0.55.

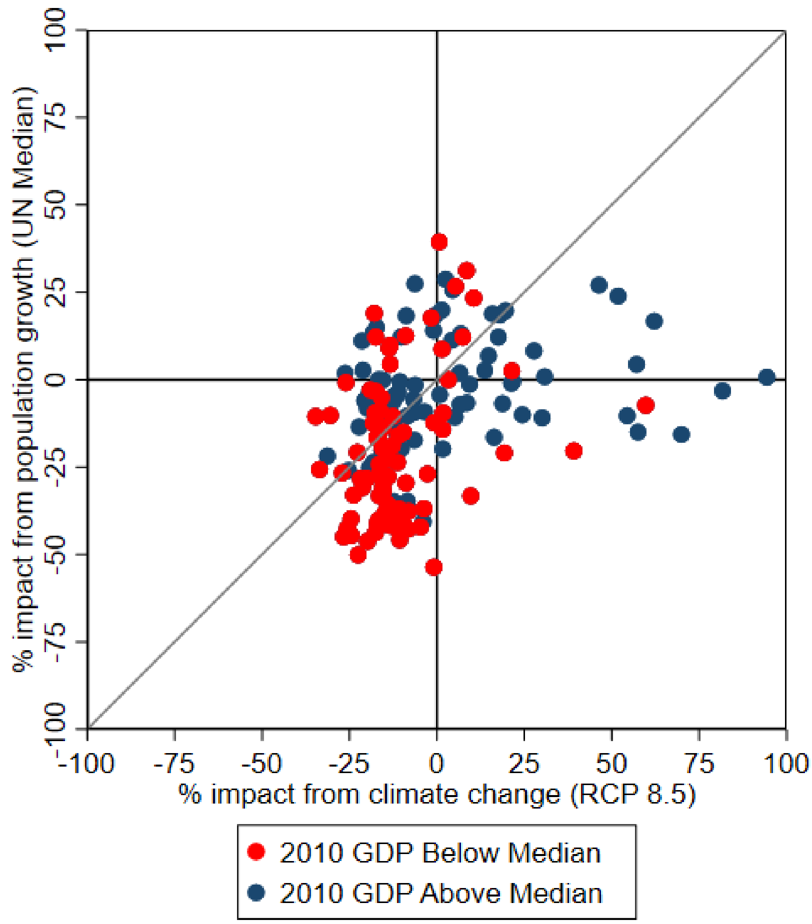
6.3 Relative Importance of Climate Change and Population Growth

The analysis above naturally raises the question of the relative magnitude of effects from climate change and population growth. In equation (14), we want to compare the first term, $\left(\frac{X_{Alt}}{X_{Base}}\right)^{\frac{\beta}{1-\alpha}}$, to the second, $\left(\frac{L_{Alt}}{L_{Base}}\right)^{\frac{-\beta}{1-\alpha}}$. However, a complete answer to this question is complicated by the fact that both of these effects enter the third term in equation (14). Fortunately, in practice, as noted above and in Appendix Table C5 this third term is of relatively minor importance.

Figure 8 looks at how these two terms vary across countries. Each country is represented by a dot, with red dots indicating countries with GDP per capita below the median. The horizontal axis measures the first term (i.e. the impact of land quality change on GDP per capita) and the vertical axis measures the second (impact of population change on GDP per capita). A full set of country values appears in Appendix C.

Countries on the 45 degree line are those for which the impacts of changes in land quality and population growth are equal. Countries below the 45 degree line have either more positive or less negative impacts of climate change than population growth, and vice versa for those above. Those negatively affected by climate change are to the left of the vertical line at 0 and are mostly low income countries, while those to the right of that line are disproportionately high income. Similarly looking at the horizontal line at 0, those countries negatively affected by population growth are disproportionately low income countries. That is, low income countries tend to suffer losses from both population growth and climate change. Quantitatively, climate losses are all under 35%, while many countries have losses from population growth that are that in the 40–50% range. These countries are mostly poor and agricultural—that is to say, more prone to suffer from congestion and declining land quality, and in a worse position to deal with the consequences of these changes. Finally we note that the gains from climate change tend to exceed gains from population

Figure 8: Changing ALQ and Population



Note: Figure compares the effect of the the second term in equation (14), which represents the impact of population growth, against the first term, which represents the impact of climate change in 2100. Impacts are calculated in percentages under mobile labor assumptions using RCP 8.5 and the U.N. medium variant population projection; 164 countries are shown.

decline.

In summary, Figure 8 makes clear that for most of countries projected to experience high levels of damage from climate and population growth taken together, the biggest source of that damage is population growth. There are a few specific countries such as Paraguay and Morocco where effects from projected population increases are much smaller than for projected declines in land quality. But for the majority of countries, the major culprit is population growth. To give a typical example, in Tanzania, the impact of declining land quality is projected to be -20%, while the impact due to rising population is projected to be -46%. It is worth recalling that all of this analysis is done using RCP 8.5, the most extreme climate scenario. As we explore further below, using projections from a less dire climate projection further elevates the relative importance of population growth as a driver of damages.

6.4 Variation Across Projections

In the analysis above, we focused on RCP 8.5, the most extreme of the four climate scenarios, along with the UN medium population projections. The fact that organizations like IPCC and the UNDP produce ranges of scenarios is indicative of the uncertainty regarding these projections. A natural implication of this is that one can learn something about the range of possible outcomes by looking at the range of scenarios.

In the case of the UNDP, they explicitly state that:

> In projecting future levels of fertility and mortality, probabilistic methods were used to reflect the uncertainty of the projections based on the historical variability of changes in each variable. The method takes into account the past experience of each country, while also reflecting uncertainty about future changes based on the past experience of other countries under similar conditions. The medium-variant projection corresponds to the median of several thousand distinct trajectories of each demographic component derived using the probabilistic model of the variability in changes over time. Prediction intervals reflect the spread in the distribution of outcomes across the projected trajectories and thus provide an assessment of the uncertainty inherent in the medium-variant projection. [20]

Unlike the UNDP data, there are no probabilities assigned to the different RCPs used to assess the effects of changing climate, nor is there any claim that the actual path of climate change will fall within the span of the four

[20]In addition to these probabilistic projections, the UNDP also provides "high" and "low" variant projections, which differ from the medium variant only setting the terminal level of the total fertility rate to be 0.5 above or below it. The relationship between these high and low variants, on the one hand, and the probabilistic bounds, on the other, varies by country. In general, in countries with high current fertility, the high and low projection variants fall within the 95% probability bounds, while the opposite it true in countries with low current fertility.

commonly used RCPs. There is an additional layer of uncertainty in that RCPs only describe the path of radiative forcing values (in Watts per square meter), while it then takes an entire climate model to generate projections of the physical outcomes of any RCP path.

All that being said, we would argue that there is still *some* information in the range of projections for each source. One might claim that in looking across the four RCPs, and similarly in comparing, say, the 5th to the 95th percentile probability population projections, one is in each case looking across the range of likely outcomes, and possibly getting some sense for the range of outcomes that different policies could achieve.

In conducting this analysis, we restrict ourselves to looking at individual countries, rather than trying to aggregate to the level of the world as a whole. We start with an example for a single country, India. Table 2 shows the percent change of GDP per capita in 2100, relative to a scenario where population and climate are unchanged. We consider four climate scenarios and five population scenarios, all under perfect population mobility. The changes with immobility follow a similar pattern.

Using the median UN forecast, India's GDP will be around 20% lower in RCP 8.5 than if both population and climate had remained the same. The main result in the table, however, is that moving across climate scenarios has a much smaller effect on the expected change in GDP per capita than does moving across population scenarios. For any given population scenario, the difference between the total impact of climate and population on GDP, comparing the most extreme climate scenarios, is about 10 percentage points. By contrast, for a fixed climate scenario, the range of impacts on GDP comparing the highest to the lowest population growth scenarios is roughly 30 percentage points.

Table 2: Impact of Climate Change and Population on GDP per Capita in India

			Climate Scenarios			
			% Change in QAA, 2010-2100			
			RCP 2.6	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**
			-17.45	**-19.31**	**-31.89**	**-40.53**
UN Pop. Projections — **% Change in Pop., 2010-2100**	**Lower 95%**	**-28.14**	6.75	6.00	0.57	-3.56
	Lower 80%	**-14.44**	-0.08	-0.78	-5.87	-9.75
	Med	**17.24**	-11.28	-11.91	-16.44	-19.89
	Upper 80%	**51.74**	-19.48	-20.05	-24.17	-27.31
	Upper 95%	**76.75**	-23.95	-24.49	-28.39	-31.36

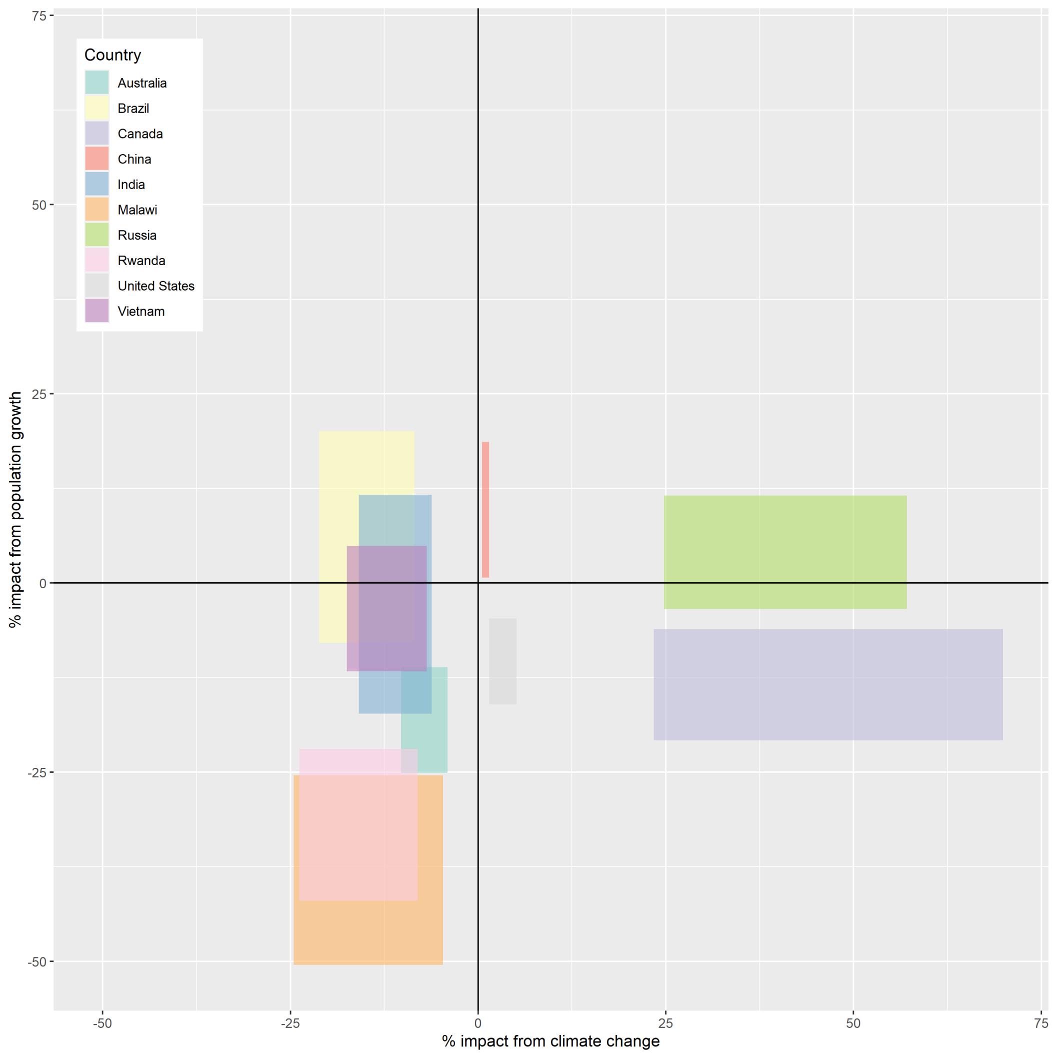
Note: The numbers in bold in the first numerical column provide the percent change in population from 2010 to 2100 for each of the five population projections provided by the UNPD. The bold numbers in bold in the first numerical row provide the percent change in ALQ from 2010 to 2100 corresponding to each RCP. The 5×4 matrix provides the percent change to GDP per capita for each population projection-climate scenario pair according to equation (14))

In the perfect mobility case, we can use equation (14) to separate out variation in climate change and population growth in the total impact. As before, we ignore the small offset term.[21] Figure 9 expands this analysis graphically to look at 10 particularly interesting countries. Each country is represented by a colored rectangle. The horizontal dimension of the rectangle shows the range in projected impacts from land quality change (the first term in equation (14)), looking across all four RCPs. The vertical dimension of the rectangle is the range of the impact from population growth (the second term of equation (14)) going from the 5th to the 95th probability percentile estimate of the change in log population between 2010 and 2100.

As an illustrative example, for Malawi, the rectangle showing the range of GDP per capita losses is much taller than it is wide, indicating that there is

[21] Values for country level damages inclusive of this term under all RCPs and population scenarios can be found in Appendix C.

Figure 9: Range of Impacts from Climate Change and Population for Selected Countries



Note: This plot depicts the minimum and maximum impacts from climate change and population across different scenarios, represented by the first and second terms of equation (14)) as percent changes. The contribution from impacts attributed to climate change come from four RCP scenarios, and scenarios for log impacts from population comprise the 95th and 80th percent confidence intervals as well as the median from UN population projections.

less uncertainty regarding the effect of climate change than there is regarding the effect of population change. The rectangle for Malawi is also entirely in the lower-left quadrant (rising population, falling land quality), indicating that, within the range of these estimates, all scenarios will lead to an increase in population pressure on quality-adjusted land. By contrast, the rectangle for Russia is wider than it is tall, i.e. there is more uncertainty about the effect of climate than about population. Russia also sits largely in the upper right quadrant, indicating that both forces will be pushing toward reduced population pressure on land.

Not only does population growth tend to contribute more than climate change to country-level GDP impacts, but variation among population scenarios also makes a good deal more difference than does variation across climate scenarios. We choose to display a limited number of countries in Figure 9 for demonstrative purposes; however, this remains the case for most countries. Results for all countries can be accessed interactively at `https://bjang.shinyapps.io/appendix_countries/`.

7 The World Damage Function

In this section, we assess the damage from climate change aggregated to the world level. Our motivation for doing this is largely for comparability with existing literature.

Aggregating the country-level climate damages calculated in Section 6 to the world level requires an additional piece of information, which is the *level* of total output in each country in 2100 in the absence of climate change. So far we have avoided this issues of levels, and calculated percent losses or gains from whatever the level might be. Now we need the actual level to be comparable to the literature. Following other work in this area, we rely on the Shared Socioeconomic Pathways (SSPs; O'Neill *et al.*, 2014; Riahi *et al.*, 2017) for these projections. These are scenarios for how the world economy might evolve in the absence of both climate change and climate mitigation or adaptation policies. The different pathways embed particular assumptions about technological change, population and economic growth, and cross-country income convergence, among other dimensions. For example, SSP 5 features the following: rapid income growth at the world level combined with a large decline in income gaps among countries, and world population peaking around the year 2060 and then declining to around 7 billion in 2100. By contrast, in SSP 3, world income growth is slow, cross-country inequality falls only slightly, and high population growth in poor countries drives the world population to 12.6 billion in 2100. SSP 2 represents a continuation of historical social, economic, and technological trends, and falls roughly in the center of the range of the other pathways in terms of income and population growth.[22]

Table 3 shows the damage function at the world level, which aggregates country losses weighted by their 2100 GDP in the absence of climate change. These GDP weights vary considerably across the SSPs. The top rows show world GDP and population under the different SSP scenarios, as well as 2010 numbers. Then, in panels A, B, and C, each entry shows the percentage change in world total GDP going from the case when climate change has no economic effects to the case where climate follows a specified RCP. Specifically, in Panel A, each entry is the weighted average of country-specific percentage changes in GDP under the particular SSP-RCP scenario assuming population mobility within countries as in equation (14) calculated above, where the weights are 2100 country values of total GDP under the specified SSP. Panels B and C show analogous numbers for the immobile labor cases where labor allocations are fixed at historical patterns and then the variant where those allocations in 2010 are efficient, as represented respectively by equations (21) and (22).

To compare these results to existing literature, Burke *et al.* (2015A) focus on the case of RCP 8.5 and SSP 5 to estimate that average global incomes would be reduced around 23%. By contrast, our projection is that world level GDP would fall by only 4.6% using the same scenarios and assuming perfect labor mobility. In Panels B and C without the mitigating effect of within country labor mobility, these losses rise to around 6.5%, still a small fraction of the Burke *et al.* (2015A) estimates.

In each panel, RCP 8.5 unsurprisingly yields the most negative impacts to world GDP in the year 2100. Within each SSP, we see that the magnitude of impact increases moderately from RCP 2.6 to RCP 6.0, then jumps with RCP 8.5. It is worth noting that not all RCPs are plausible in each SSP. For example, it is highly unlikely that RCP 2.6 or even RCP 4.5 will be reached under the baseline SSP5 scenario. Comparison of RCPs across different SSPs must therefore be done with care. Impacts as percentage of world GDP in RCP 8.5 are higher in SSP1, the sustainability-focused scenario, than SSP5, the fossil fueled development scenario, due to the differences in convergence of world incomes under each narrative.

As suggested above, impacts calculated assuming perfect labor mobility in 2100 tend to be lower than those calculated assuming complete immobility,

[22]Projections of population, urbanization, and GDP that quantify the narratives of the Shared Socioeconomic Pathways are available in a database hosted by the International Institute for Applied Systems Analysis (IIASA) Energy Program at `https://tntcat.iiasa.ac.at/SspDb`. We use the projections of the Organization for Economic Co-operation and Development (OECD; Dellink *et al.*, 2017), considered the "illustrative" case. Population projections for each SSP are from Samir and Lutz (2017).

Table 3: 2100 Impacts as Percentage of World GDP (OECD Env-Growth)

Year	2100					2010
Scenario	SSP 1	SSP 2	SSP 3	SSP 4	SSP 5	
	Sustainability – Taking the Green Road	Middle of the Road	Regional Rivalry – A Rocky Road	Inequality – A Road Divided	Fossil-fueled Development – Taking the Highway	Historical Data
World GDP	5.65e+14	5.38e+14	2.78e+14	3.53e+14	1.02e+15	6.73e+13
World Pop.	6.87e+09	8.98e+09	1.26e+10	9.25e+09	7.35e+09	6.85e+09
A. % Impacts: Mobile Labor						
RCP 2.6	-1.582	-1.633	-1.539	-0.800	-1.070	0.727
RCP 4.5	-2.202	-2.255	-2.143	-0.978	-1.403	1.452
RCP 6.0	-3.392	-3.398	-3.163	-1.672	-2.349	1.878
RCP 8.5	-6.173	-6.134	-5.729	-3.392	-4.594	2.076
B. % Impacts: Immobile Labor, Historical Allocation						
RCP 2.6	-1.980	-2.023	-1.951	-1.294	-1.554	0.070
RCP 4.5	-2.835	-2.887	-2.829	-1.764	-2.166	0.395
RCP 6.0	-4.147	-4.152	-3.981	-2.656	-3.271	0.536
RCP 8.5	-7.787	-7.734	-7.439	-5.419	-6.515	-0.653
C. % Impacts: Immobile Labor, Initially Efficient Allocation						
RCP 2.6	-2.025	-2.079	-2.009	-1.313	-1.543	0.127
RCP 4.5	-2.938	-3.001	-2.952	-1.868	-2.203	0.354
RCP 6.0	-4.312	-4.327	-4.171	-2.798	-3.357	0.475
RCP 8.5	-7.853	-7.829	-7.588	-5.485	-6.448	-0.544

as gains in warming Northern countries occur in grid cells with relatively low human activity, making the immobile labor distribution less efficient. We can capture the mitigating effect of within-country migration by comparing panel (a) with panel (c), in which labor is distributed efficiently in 2010 and fixed there to 2100. In SSP3 the worldwide negative impact of RCP 8.5 changes from -5.73% to -7.59%. As noted above in the comparison with Burke *et al.* (2015A), in SSP5 it changes from -4.59% to -6.45%. It makes sense that all impacts are more negative if migration does not occur. Our assumption of perfect internal mobility in the baseline incorporates this mitigation measure into our specification, leading to the estimation of less severe projected impacts.

8 Conclusion

This paper quantifies the projected effects of established climate change scenarios on characteristics that affect the carrying capacity of land, which we call land quality. Land quality tends to increase for select countries in currently colder climates and decreases in the tropics. Using this measure in a model of economic growth, we assess the effects of climate change against a counterfactual in which land quality is unchanged. Under the most extreme scenario of RCP 8.5, we estimate country-level impacts ranging from -33% to 87%, with a positive correlation between log GDP and climate change impact so that richer countries on average experience more positive impacts.

We further compare the effects of climate change against the effects of projected population growth, finding that the impact of the latter is consistently the larger of the two. Further, the difference in economic outcomes comparing the most extreme to the most modest climate scenarios is, for most countries, smaller than the difference in economic outcomes comparing the highest to the lowest population growth scenarios.

Our analysis of climate damages is closely tied to the output of global climate models, and thus shares any limitations that are present in these models. Notably, this means that our analysis may under weigh the importance of natural disasters that are likely to become more frequent with global warming.

One of our crucial findings is that climate change will make the natural environment less supportive of human habitation in exactly the places where population growth is already working to raise the burden on that land. The intensification of population pressure disproportionately affects more vulnerable regions, becoming another driver for inequality in economic development.

A simple reading of our results would say "Don't worry about climate change–the bigger issue is population growth." This is not our interpretation, for several reasons. First, even a finding that population growth is a larger driver of environmental stress than climate change does not in any way lessen the damage being done by that climate change. Second, unlike the effects of population growth, the effects of climate change largely result from decisions and behaviors outside the country that is impacted. More concretely, in poor countries that will suffer the most from climate change, the vast majority of relevant emissions causing that climate change were the result of economic activity elsewhere in the world. Third, nothing in our analysis addresses the relative costs and unintended consequences of reducing population growth versus mitigating climate change. Finally, the welfare calculus regarding population growth differs markedly from that regarding climate change: having more warming, holding population constant, reduces the average welfare of a fixed set of people. By contrast, reducing population growth, holding climate constant, may raise welfare per capita but lower then number of people who experience that welfare.

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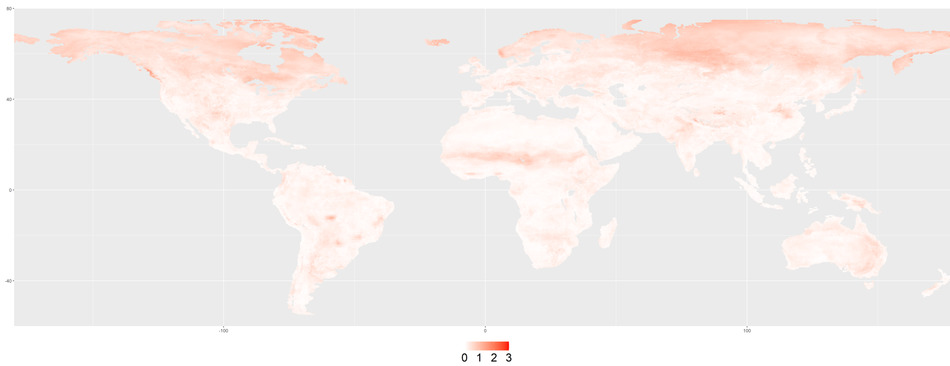
A Variation Across Climate Models

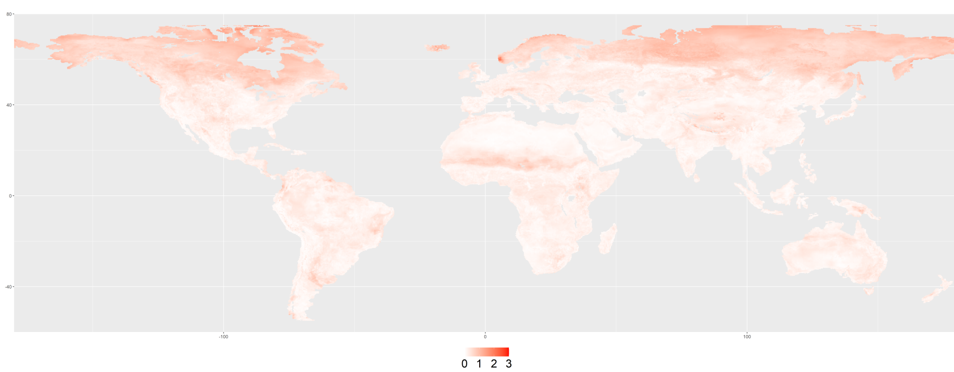
As mentioned in the methodology, the main results in this paper rely on the ensemble mean of five climate model forecasts. Here we discuss the variation in projections across these forecasts in more detail. Appendix Figure A1 shows the grid-level standard deviation of our projected land quality measure across the five climate models included in this paper.

Figure A1: Changing *ALQ* and Population

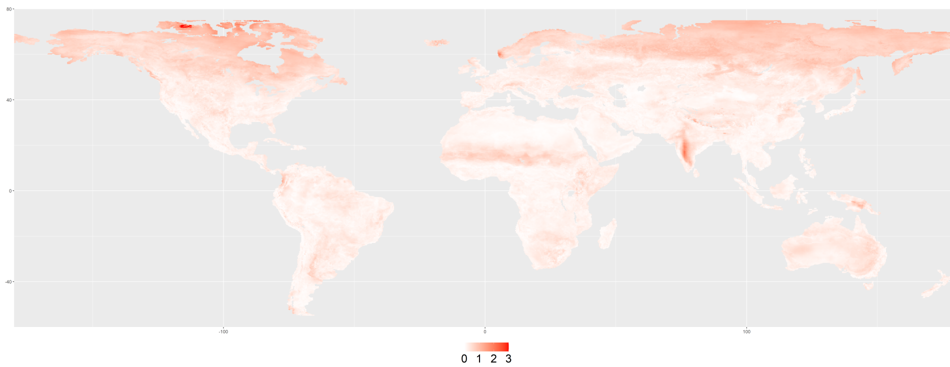
(a) RCP 2.6



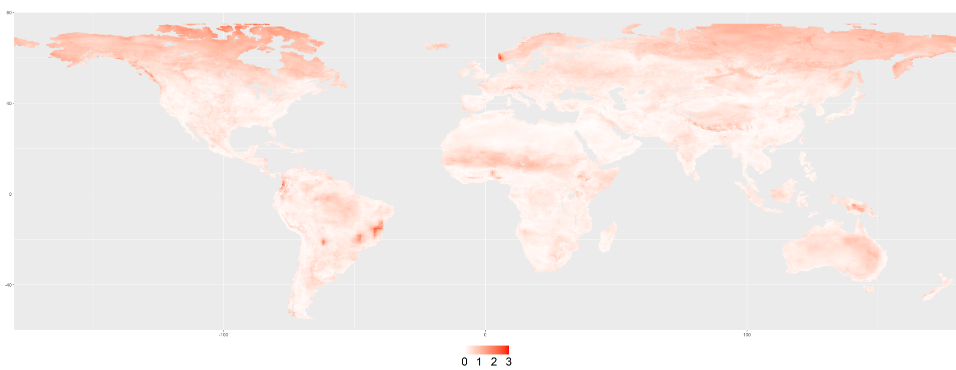
(b) RCP 4.5



(c) RCP 6.0



(d) RCP 8.5



Note: Values are censored to 3 for visualization.

In general, the largest variation among models is in the northern part of the Northern hemisphere as well as the Sahara Desert, although there are other, more localized areas of disagreement as well in specific climate scenarios. Specifically, we see high variation in the Western Ghats for RCP 6.0 and in Minas Gerais in Brazil for RCP 8.5. Both of these are driven by unusually negative values from a single model (MIROC).

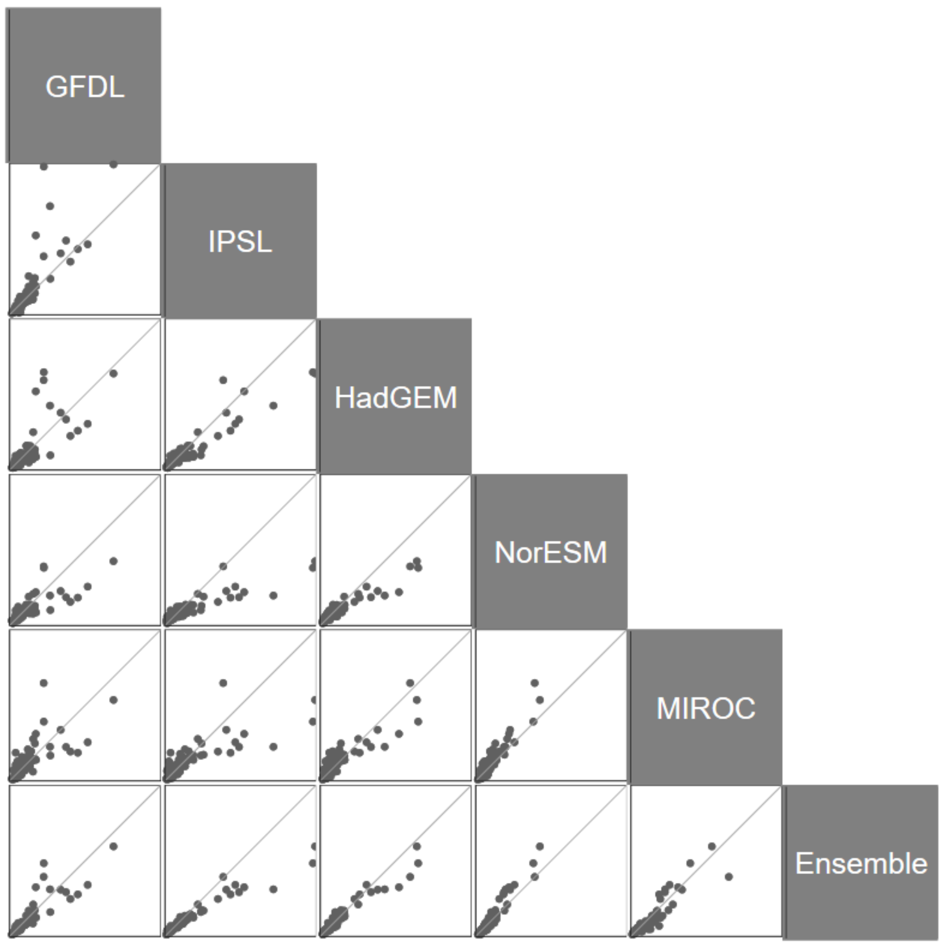
For each climate model we also calculate country-level projected changes in average land quality over the period 2010-2100 under the RCP 8.5 scenario. These are presented in Appendix Figure A2, where Panel (a) uses area-weighted ALQ, while (b) uses population-weighted ALQ. The two panels are similar. In general, these country level projections are highly correlated among the different climate models and each is well correlated with the ensemble mean. However, there are notably larger cross-models differences in projections for countries that are expected to have improved average land quality in the north-east of each graph, which also tend to be richer countries. Among countries where land quality is expected to decline, there is more accord among the models.

While within-model uncertainty–either from parameters or initial conditions–must also be acknowledged for each climate model, we are not equipped to address this additional source of uncertainty.[23]

[23] The IPCC Assessment Report 4 discusses these issues and the degree of uncertainty they impart in section 10.5. The confidence intervals reported for projections in IPCC Assessment Report 5 are estimated by assuming each model's point estimate is pulled from one normal distribution with same mean and standard deviation.

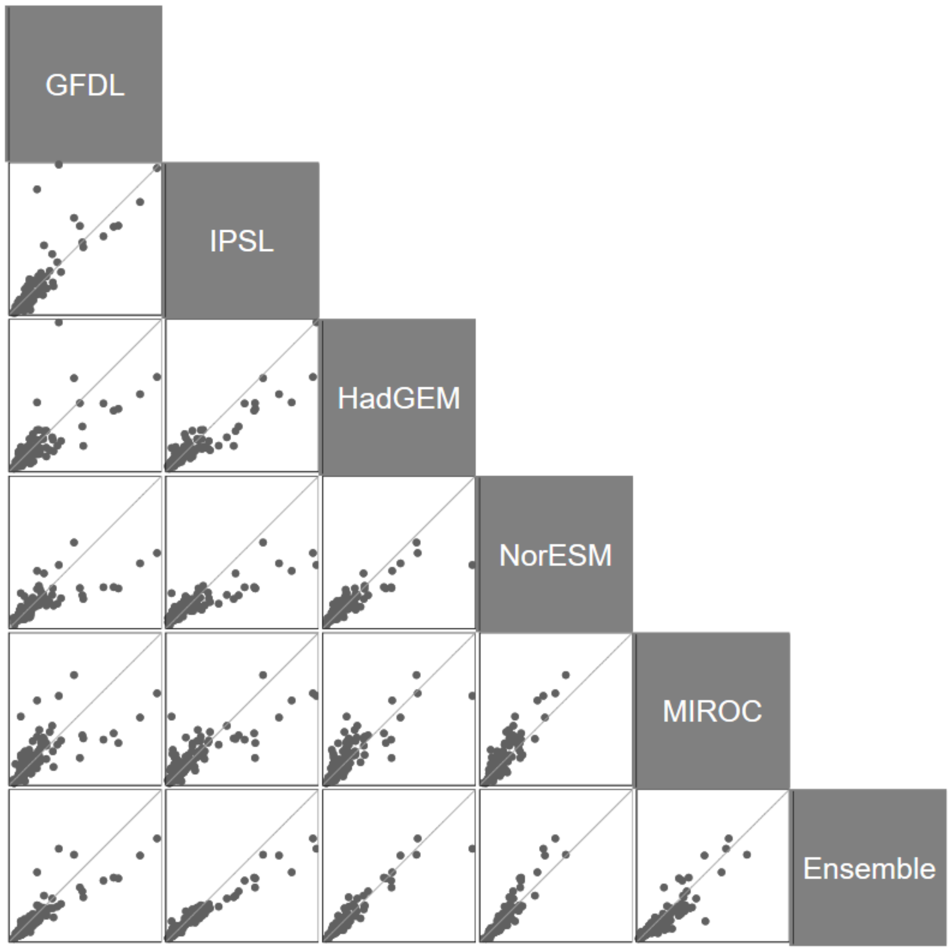
Figure A2: Comparison of changes to *ALQ* by Climate Model

(a) Area-weighted *ALQ*



Note: Each cell of this matrix depicts a scatterplot comparing the percent change in ALQ from 2010 to 2100 projected by two different models. The range of each axis is fixed at -88 to 559 percent. The diagonal represents the 45 degree line.

(b) 2010 Population-weighted *ALQ*



Note: Each cell of this matrix depicts a scatterplot comparing the percent change in ALQ from 2010 to 2100 projected by two different models. The range of each axis is fixed at -88 to 559 percent. The diagonal represents the 45 degree line.

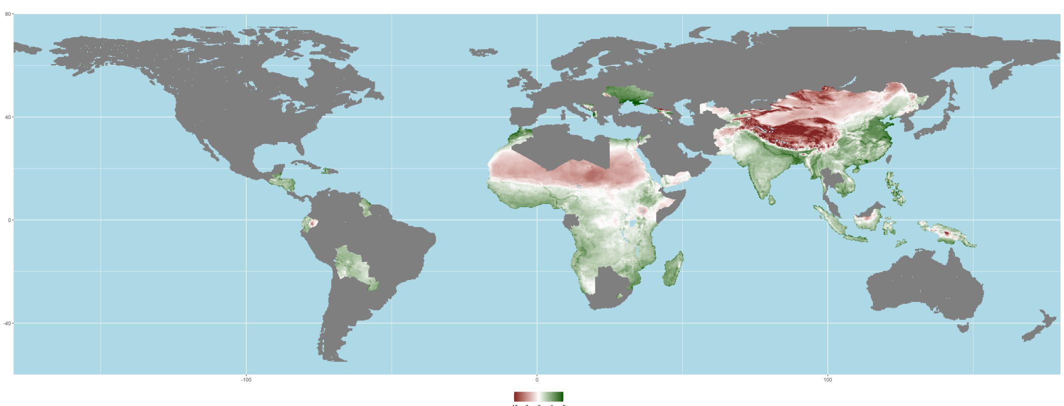
B Robustness of Measured *ALQ* Changes to Choice of Sample Countries.

One concern regarding our grid-cell regression is that countries may value the land characteristics included in our regression differently depending on their stage of development. As a robustness check, we replicate our main results on the effect of projected climate change on land quality, focusing on a sample of poor countries. Specifically, we re-estimate our grid-cell level Poisson regressions for measuring land quality on the sample of all countries with below-median GDP per capita, and then use estimated coefficients to form projections of the change in land quality due to climate change for this subsample of countries. The logic behind this exercise is that the value of specific land characteristics in determining economic outcomes may be a function of the level of a country's development. Correspondingly, the effect of a change in a particular characteristic will have a different effect in poor vs. rich countries. For example, a reduction in rainfall in an already dry climate could be devastating in a region reliant on smallholder agriculture, but in a developed region that imports its food from elsewhere it would have only a marginal effect.

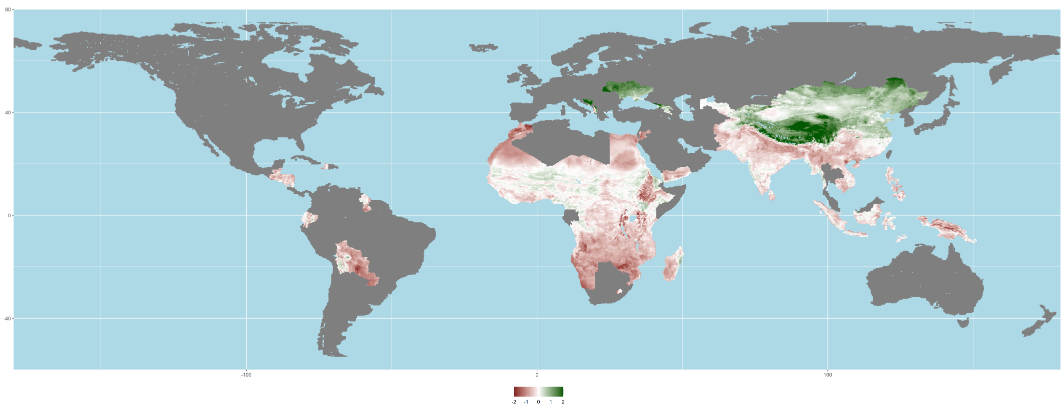
The analysis above showed that it is generally in poor countries that climate change is expected to have the most negative effects. Furthermore, poor countries generally have fewer opportunities to substitute production away from climate-affected sectors, since they are heavily reliant on agriculture and primarily consume domestically produced food. Finally, large fractions of the populations of poor countries face high transportation costs in interacting with the broader world economy.

Figure B3: Log Land Quality, Countries with Below-Median GDP Only

(a) Historical Log Land Quality



(b) Differences between Historical and 2081-2100 Log Land Quality under RCP 8.5

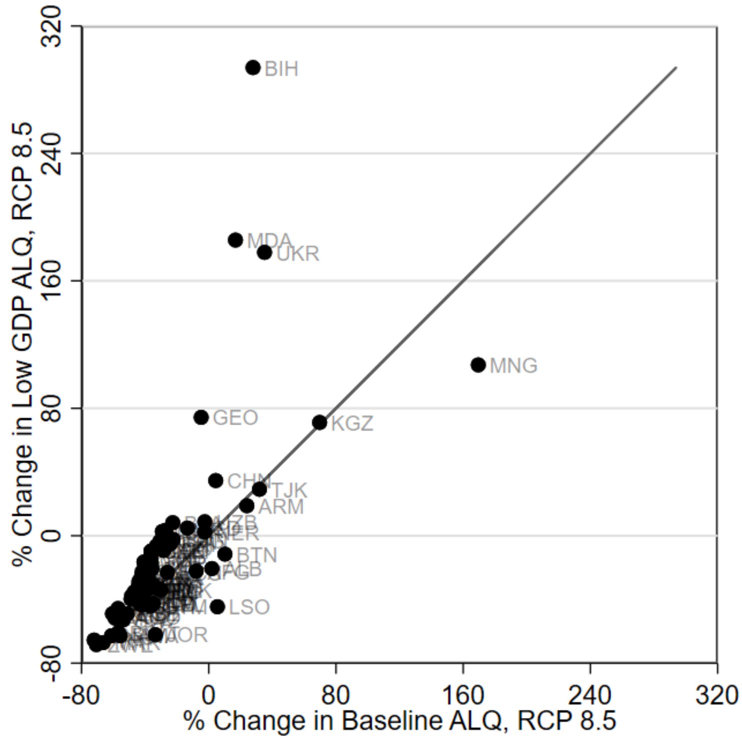


Note: Data are censored at -6 and 4 and at -2 and 2 in the top and bottom panels, respectively, for visualization. Plate Carrée projection.

Figure B3 is analogous to Figure 1, except that it bases estimates on and looks only at countries with current GDP per capita below the world median of $9,698. The first panel shows estimated values for grid-cell level land quality using this new estimation sample, while the second panel shows projected changes in land quality between 2010 and 2100 under RCP 8.5. For the relevant countries, the (b) panels of Figures 1 and B3 seem very similar, with improvements in the Tibetan Plateau and parts of China and deterioration for most Africa and South and South-East Asia.

Figure B4 shows data on changes in land quality over the period 2010-2100 under RCP 8.5, comparing projections based on coefficients derived from the full sample (horizontal axis) and from the sample of below-median income countries (vertical axis). The data are aggregated to the country level using area weights. Doing this comparison using population-weighted projections yields a very similar result.

Figure B4: Comparing Change of Baseline *ALQ* and Below-Median GDP *ALQ*



Note: Figure plots the percent change in baseline ALQ from 2010 to 2100 in RCP 8.5 against that of ALQ estimated using only countries with below-median GDP for the 78 countries with both values.

Overall, Figure B4 shows that the predicted effects of climate change are fairly similar using the two different approaches. There are 10 countries that are projected to have decreased *ALQ* using the full sample estimates but increased *ALQ* using the below-median sample estimates, and 3 countries that are expected to have the reverse. However in almost all of these cases, the projected changes in *ALQ* are not far from zero. Most countries that are projected to suffer severe declines in land quality under one measure are projected to suffer similar declines under the other. The correspondence between the two projections is fairly tight for the majority of countries that will experience deterioration, but more scattered among those where land quality will improve.

Given this result, we use projections of the effect of climate change based on full-sample estimates for the main body of the paper.

C Data Tables

C.1 Baseline

Table C1: Changes in ALQ by RCP

	Historical ALQ	% Change in ALQ, 2010 - 2100							
		Area weighted				Pop. weighted			
Country		RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Afghanistan	0.20	11.00	-0.08	0.92	-7.92	8.59	-0.13	2.74	-5.30
Albania	2.60	-6.49	-5.60	-1.84	1.95	-7.35	-10.14	-4.52	1.28
Algeria	0.33	-17.38	-26.25	-30.05	-40.37	-25.10	-33.98	-38.68	-46.71
Angola	1.56	-25.00	-33.28	-38.33	-53.54	-23.14	-19.09	-25.15	-38.31
Argentina	2.96	-7.70	-14.16	-14.52	-23.22	-14.82	-21.44	-21.69	-28.37
Armenia	0.64	16.10	17.17	19.63	23.96	-1.22	-7.73	-1.85	-1.95
Australia	1.39	-11.77	-14.20	-14.48	-27.67	-18.27	-18.14	-15.53	-34.15
Austria	1.76	26.02	43.83	55.27	78.42	18.51	34.22	41.55	50.54
Azerbaijan	2.90	-2.13	-20.16	-23.50	-28.47	-3.44	-20.86	-24.28	-30.97
Bangladesh	3.18	-29.84	-44.20	-43.57	-59.53	-31.24	-45.28	-44.60	-61.03
Belarus	3.27	56.75	85.70	94.14	108.59	54.80	79.61	87.55	102.49
Belgium	11.47	-13.16	-22.73	-10.89	2.46	-19.10	-29.22	-15.11	-2.13
Belize	1.79	-25.90	-27.62	-28.49	-39.83	-25.31	-29.78	-28.96	-41.24
Benin	0.96	-8.04	-7.47	-17.43	-32.95	-10.61	-13.82	-25.49	-40.03
Bhutan	0.23	1.95	7.47	4.75	10.17	1.87	-1.08	-7.21	-13.69
Bolivia	0.84	-20.68	-22.89	-30.18	-42.33	4.06	10.61	8.55	5.34
Bosnia and Herzegovina	2.07	14.96	25.01	36.04	27.83	13.42	24.11	35.57	23.51
Botswana	0.51	-13.75	-46.49	-44.94	-67.63	-4.03	-42.74	-38.54	-69.94
Brazil	1.09	-23.36	-28.00	-34.69	-51.00	-24.35	-25.48	-32.33	-48.43
Brunei	0.73	7.51	7.47	-9.50	-39.64	10.25	11.52	-7.23	-40.89
Bulgaria	4.85	8.31	9.37	9.56	-17.73	6.29	7.38	10.36	-17.44
Burkina Faso	0.36	-2.74	-5.88	-7.12	-22.64	-3.72	-7.70	-8.20	-25.34
Burundi	0.83	-22.44	-35.33	-40.96	-56.91	-21.82	-34.72	-40.68	-56.33
Cambodia	1.29	-20.29	-27.43	-33.90	-45.25	-22.41	-30.55	-37.20	-49.35
Cameroon	0.90	-6.63	-3.30	-13.58	-27.19	-5.11	-1.49	-11.05	-23.15
Canada	0.17	87.84	173.37	220.65	390.58	4.76	27.68	40.81	68.42
Central African Republic	0.48	-13.00	-13.36	-20.92	-36.29	-9.83	-9.71	-18.15	-34.95
Chad	0.11	4.15	4.22	5.30	-13.45	-0.84	0.73	0.14	-17.60
Chile	1.45	24.06	39.12	48.83	80.16	34.63	52.61	60.84	64.77
China	0.81	2.54	1.55	2.86	4.38	-3.42	-9.47	-8.72	-14.20
Colombia	0.58	-12.16	-17.23	-24.98	-42.06	-9.82	-17.46	-20.23	-39.82
Costa Rica	0.78	-12.63	-0.29	-11.62	-17.57	-12.24	1.34	-9.78	-4.86
Croatia	5.67	14.15	22.35	31.88	14.05	14.86	22.36	32.26	11.48
Cuba	3.39	-21.88	-30.84	-32.96	-44.68	-16.21	-29.96	-33.77	-44.83

Czech Republic	3.26	55.39	78.61	90.20	123.91	44.98	64.85	73.26	96.95
Democratic Republic of the Congo	0.63	-10.82	-12.30	-22.93	-43.88	-14.30	-17.46	-26.51	-46.53
Denmark	13.65	38.40	49.86	63.23	67.57	43.77	55.61	68.51	74.01
Djibouti	0.23	1.30	-4.12	4.70	5.05	6.79	2.27	12.69	4.42
Dominican Republic	3.23	-27.89	-34.39	-36.15	-47.66	-29.21	-38.76	-40.65	-55.32
Ecuador	0.96	-1.95	-5.34	-9.74	-26.02	-5.36	-9.56	-12.51	-27.95
Egypt	0.31	-22.30	-33.50	-37.85	-52.27	-28.55	-40.48	-45.06	-58.47
El Salvador	1.13	-17.93	-20.53	-24.79	-35.74	-18.04	-18.83	-22.84	-35.01
Equatorial Guinea	0.99	-2.09	8.56	-1.02	-11.44	-2.79	5.07	-4.36	-17.79
Eritrea	0.33	-7.61	-19.54	-15.31	-24.30	-6.15	-25.12	-21.08	-33.34
Estonia	2.09	137.41	234.11	277.28	326.33	112.23	200.56	236.56	278.86
Ethiopia	0.72	-12.50	-23.34	-27.35	-41.74	-8.92	-22.71	-26.30	-44.84
Finland	0.76	143.79	296.41	401.39	634.30	98.91	188.31	269.48	350.86
France	6.73	0.98	14.90	13.42	30.76	3.62	16.45	12.54	31.32
French Guiana	0.80	-1.06	3.22	-5.93	-10.87	2.73	6.77	-2.26	-9.80
Gabon	1.06	-5.63	2.87	-6.26	-23.26	-8.20	0.53	-9.53	-24.62
Gambia	0.85	-12.29	-19.36	-25.36	-40.78	-16.52	-24.63	-29.57	-49.51
Georgia	1.77	5.45	0.58	-0.86	-4.76	7.46	0.65	-0.33	-11.40
Germany	7.11	27.43	31.49	33.17	46.85	16.99	19.06	21.15	32.57
Ghana	1.12	-15.49	-15.26	-24.25	-39.40	-13.52	-15.76	-26.56	-45.61
Greece	4.77	-8.80	-14.50	-10.12	-24.10	-7.92	-18.22	-15.92	-33.11
Guatemala	1.20	-23.24	-26.29	-27.08	-36.70	-24.91	-25.37	-26.94	-36.78
Guinea	0.91	-18.91	-21.28	-27.89	-38.12	-19.69	-20.81	-28.66	-38.13
Guinea-Bissau	1.08	-5.60	-16.91	-20.80	-36.53	-4.37	-16.71	-20.48	-36.71
Guyana	1.03	-13.52	-23.37	-26.63	-43.82	-15.23	-27.56	-28.48	-47.24
Haiti	2.34	-22.27	-30.65	-31.89	-44.16	-21.09	-29.14	-32.28	-44.75
Honduras	1.40	-25.63	-29.89	-33.04	-43.23	-24.93	-32.47	-35.61	-47.23
Hong Kong	6.52	-19.97	-26.56	-35.21	-47.31	-20.89	-27.54	-36.03	-48.27
Hungary	4.93	26.28	38.98	49.84	21.99	27.50	39.92	50.12	24.31
Iceland	0.34	116.28	224.65	286.56	499.63	32.37	99.44	115.37	208.05
India	1.22	-17.45	-19.31	-31.89	-40.53	-23.55	-24.97	-34.99	-46.28
Indonesia	0.85	-0.39	-5.09	-15.91	-41.19	-2.26	-7.33	-19.66	-47.20
Iran	0.41	5.09	-4.19	-4.97	-10.17	3.01	-2.86	-2.89	-3.74
Iraq	0.50	-1.43	-12.20	-17.69	-32.56	-8.06	-18.03	-24.07	-36.34
Ireland	6.36	8.98	11.54	22.47	21.14	5.61	6.18	12.77	9.82
Israel	2.42	-10.80	-31.04	-34.12	-58.22	-1.86	-26.31	-29.55	-57.23
Italy	4.69	5.72	9.14	11.06	-2.86	10.53	14.47	15.67	-4.08
Ivory Coast	1.31	-16.42	-12.81	-23.11	-42.21	-16.62	-13.71	-21.29	-43.72
Japan	1.68	20.78	28.87	47.61	71.17	13.97	9.79	18.82	27.84
Jordan	0.40	-8.90	-19.75	-20.73	-33.58	-8.22	-23.23	-25.44	-44.84
Kazakhstan	0.22	44.93	51.39	40.19	57.55	34.25	42.07	33.73	51.52
Kenya	0.69	-6.78	-14.93	-21.16	-39.68	-15.53	-25.80	-31.24	-49.71
Kuwait	0.32	-9.33	-21.00	-28.63	-38.79	-5.87	-19.44	-26.29	-36.84
Kyrgyzstan	0.09	35.96	52.56	51.26	69.74	27.65	40.05	32.71	43.09
Laos	0.90	-20.78	-33.30	-30.79	-44.12	-23.21	-35.79	-33.03	-46.21

Latvia	2.81	124.83	187.77	212.24	250.09	89.49	139.01	161.17	182.09
Lebanon	3.11	-8.04	-17.41	-17.84	-32.23	-10.76	-21.06	-21.62	-37.29
Lesotho	0.94	15.67	16.55	26.65	5.45	19.97	17.60	25.26	-16.84
Liberia	1.16	-3.62	-5.48	-16.63	-29.23	-3.42	-4.29	-14.47	-27.50
Libya	0.29	-19.04	-28.80	-33.71	-48.56	-20.58	-33.25	-41.02	-56.90
Liechtenstein	0.07	14.63	107.36	133.90	307.53	14.63	107.36	133.90	307.53
Lithuania	2.99	116.15	159.51	172.25	213.45	100.12	135.35	154.46	185.32
Luxembourg	4.03	18.18	10.41	3.24	5.08	11.42	-1.93	-5.82	-4.87
Macedonia	1.92	6.85	9.25	17.51	-1.46	8.92	11.20	20.53	1.69
Madagascar	2.42	-15.14	-22.12	-26.93	-41.95	-10.83	-16.92	-19.91	-35.81
Malawi	1.57	-13.44	-36.60	-42.40	-57.06	-13.18	-37.63	-43.41	-58.13
Malaysia	0.79	0.32	-1.29	-10.92	-31.41	-0.28	-0.45	-11.32	-37.53
Mali	0.15	-1.14	-6.03	-8.89	-28.37	-3.82	-6.00	-10.67	-29.57
Mauritania	0.07	-10.50	-23.65	-23.72	-42.91	-1.67	-14.39	-9.77	-30.62
Mexico	1.46	-13.00	-23.49	-26.44	-42.96	-14.68	-16.77	-22.50	-43.41
Moldova	4.61	28.53	51.40	50.67	16.81	26.08	51.76	52.38	17.28
Mongolia	0.06	69.10	102.48	116.22	169.48	103.26	158.56	198.23	282.24
Montenegro	1.40	-8.42	-5.82	-4.44	13.32	-8.79	-6.67	-3.88	11.92
Morocco	1.31	-24.27	-42.81	-47.36	-66.38	-27.03	-45.57	-49.72	-72.78
Mozambique	1.88	-18.27	-35.05	-41.43	-58.84	-14.36	-31.41	-37.38	-55.88
Myanmar	1.46	-26.10	-36.28	-33.38	-46.90	-22.70	-33.38	-29.46	-41.12
Namibia	0.69	-21.97	-41.29	-42.11	-61.21	-18.98	-39.86	-40.48	-61.82
Nepal	0.69	-16.83	-16.38	-21.79	-34.97	-21.71	-24.37	-30.20	-46.51
Netherlands	19.77	2.76	-8.43	-5.08	20.94	3.37	-10.08	-6.98	22.53
New Zealand	5.49	21.04	35.39	62.14	92.64	6.75	29.72	57.71	55.94
Nicaragua	1.27	-21.78	-8.75	-19.67	-33.31	-21.86	-22.41	-28.36	-41.51
Niger	0.07	16.89	14.64	18.85	-2.62	20.59	24.57	27.95	0.96
Nigeria	0.79	-8.04	-8.81	-17.12	-30.76	-9.20	-10.78	-19.83	-35.49
North Korea	1.10	34.22	53.61	57.45	79.01	28.79	43.07	49.68	59.33
Norway	0.27	68.75	160.34	207.29	290.64	48.94	115.04	145.20	143.78
Oman	0.35	-23.26	-35.34	-36.23	-47.44	-14.84	-25.05	-28.01	-33.85
Pakistan	0.41	-7.31	-20.29	-20.23	-30.11	-16.13	-32.30	-31.70	-41.15
Palestine	2.11	-13.88	-27.85	-30.51	-51.22	-11.35	-24.97	-27.33	-48.59
Panama	1.23	-9.27	-2.34	-11.42	-18.21	-4.47	5.46	-6.08	-16.33
Papua New Guinea	0.80	-8.10	-14.33	-28.15	-48.89	-11.57	-19.44	-30.25	-49.69
Paraguay	1.47	-31.78	-35.60	-46.06	-72.11	-24.16	-27.73	-43.72	-70.02
Peru	0.67	-2.47	-3.98	-9.46	-18.54	-13.71	-17.08	-17.48	-21.95
Philippines	1.56	-11.15	-14.54	-24.71	-39.30	-16.37	-20.53	-30.39	-45.91
Poland	6.26	45.92	59.97	64.10	64.54	43.57	57.56	61.27	62.98
Portugal	8.10	-21.13	-27.38	-27.76	-43.35	-21.31	-26.95	-27.29	-43.28
Qatar	0.44	-18.56	-26.87	-33.07	-45.06	-19.21	-28.01	-33.95	-46.47
Republic of Congo	1.10	-2.91	2.56	-8.52	-26.90	-2.67	-1.86	-9.04	-28.08
Romania	4.60	19.82	21.63	25.71	4.17	15.23	15.78	17.52	-4.92
Russia	0.26	94.14	156.47	183.71	287.74	59.90	87.70	101.01	127.53
Rwanda	0.81	-22.22	-35.43	-41.82	-55.74	-21.11	-35.80	-42.32	-56.07
Saudi Arabia	0.17	-11.52	-23.11	-24.21	-38.72	-6.72	-18.40	-18.30	-31.54
Senegal	0.45	-9.69	-17.90	-20.03	-36.15	-15.38	-26.75	-29.44	-44.98
Serbia	3.65	19.76	28.25	42.83	7.59	16.79	24.66	41.44	2.12

Sierra Leone	0.98	-23.38	-27.44	-34.89	-41.86	-22.98	-26.23	-32.89	-40.22
Singapore	3.28	4.42	12.53	0.31	-29.67	4.42	12.53	0.31	-29.67
Slovakia	2.44	34.11	52.60	55.61	62.48	31.54	48.43	50.76	56.03
Slovenia	1.78	10.37	34.37	46.07	51.28	7.33	31.88	42.68	44.61
Somalia	0.26	-12.89	-25.52	-23.15	-28.67	-13.97	-26.76	-24.89	-35.97
South Africa	2.00	-6.71	-25.78	-25.89	-53.00	-15.06	-34.63	-35.82	-58.02
South Korea	2.05	34.64	45.57	57.46	55.65	36.98	47.26	59.32	58.39
Spain	3.67	-8.26	-14.50	-14.32	-27.67	-5.73	-11.28	-10.53	-27.77
Sri Lanka	1.65	-14.80	-16.92	-21.51	-34.89	-16.76	-19.79	-23.44	-38.48
Sudan	0.16	-6.81	-8.74	-6.75	-22.42	-5.66	-8.54	-4.93	-19.65
Suriname	0.97	-8.36	-13.39	-22.40	-31.06	-13.93	-20.63	-29.62	-38.05
Swaziland	3.04	-13.70	-31.32	-32.22	-53.95	-16.18	-33.30	-34.81	-55.21
Sweden	1.50	74.88	149.06	191.01	268.10	64.79	120.09	152.69	172.68
Switzerland	0.65	25.74	69.68	83.61	120.18	22.63	63.83	77.67	109.01
Syria	0.89	-13.67	-21.71	-21.03	-29.78	-16.38	-25.40	-21.99	-29.66
Taiwan	2.34	-2.88	-13.51	-16.27	-24.51	-5.65	-17.41	-18.79	-29.86
Tajikistan	0.21	11.59	17.72	22.47	31.89	5.74	11.27	15.23	22.76
Tanzania	1.23	-14.03	-26.08	-32.94	-48.50	-8.43	-18.07	-24.35	-40.72
Thailand	1.07	-24.90	-32.21	-34.48	-45.26	-28.12	-31.88	-39.05	-48.23
Timor-Leste	1.70	-12.12	-19.34	-22.50	-36.07	-12.29	-19.95	-23.80	-36.17
Togo	1.07	-8.05	-9.41	-21.00	-32.74	-8.13	-10.16	-22.15	-35.84
Trinidad and Tobago	3.33	-26.29	-25.01	-34.02	-51.51	-27.90	-26.93	-35.70	-51.39
Tunisia	1.82	-12.32	-18.42	-24.37	-33.27	-22.71	-29.33	-35.10	-43.47
Turkey	1.89	-2.68	-8.86	-5.41	-18.77	-15.52	-18.84	-13.45	-22.60
Turkmenistan	0.35	-11.71	-18.60	-23.41	-30.14	-9.85	-14.95	-19.82	-27.62
Uganda	0.59	-18.76	-16.13	-26.40	-38.26	-23.64	-22.40	-31.45	-43.28
Ukraine	4.13	35.75	43.47	51.38	35.07	37.07	42.40	49.04	32.87
United Arab Emirates	0.24	-5.22	-14.54	-20.07	-34.31	-7.37	-20.74	-28.15	-40.52
United Kingdom	7.71	11.63	13.18	20.93	27.98	5.67	5.92	10.26	17.65
United States	1.47	4.47	7.30	9.26	16.20	-8.27	-6.14	-5.52	-6.37
Uruguay	10.32	-36.75	-48.09	-49.01	-59.88	-32.36	-49.38	-46.96	-59.46
Uzbekistan	0.28	-1.75	0.04	-1.61	-2.52	4.08	9.96	9.55	13.10
Venezuela	1.00	-20.82	-26.00	-33.04	-50.10	-26.88	-34.04	-39.72	-58.11
Vietnam	1.58	-19.16	-27.51	-29.42	-43.76	-22.77	-33.10	-34.87	-51.08
Yemen	0.35	-19.14	-32.19	-30.46	-41.75	-4.76	-17.89	-13.40	-24.71
Zambia	0.94	-22.97	-39.05	-44.51	-60.60	-21.70	-39.43	-44.74	-61.24
Zimbabwe	1.46	-26.56	-49.48	-52.56	-70.67	-29.23	-53.56	-56.78	-72.41

Table C2: Country-Level Impacts of Climate Change

	% Impact on 2100 GDP												
	Mobile Labor				Immobile Labor, Hist.				Immobile Labor, Initially Efficient				Burke et al. (2015)
Country	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	RCP 8.5
Afghanistan	3.33	-0.03	0.29	-2.56	3.39	0.71	1.32	-1.18	3.12	-0.44	-0.19	-3.47	-35.96
Angola	-8.69	-12.01	-14.16	-21.50	-8.12	-9.99	-12.40	-19.04	-8.95	-12.31	-14.46	-21.93	-84.74
Albania	-2.05	-1.76	-0.57	0.60	-1.08	-1.08	0.16	1.22	-2.17	-1.95	-0.71	0.52	-33.22
United Arab Emirates	-1.66	-4.79	-6.76	-12.30	-1.70	-6.21	-8.70	-14.15	-1.70	-4.91	-6.92	-12.48	-93.91
Argentina	-2.47	-4.66	-4.78	-7.92	-4.38	-7.03	-7.83	-12.52	-3.09	-5.54	-5.98	-10.06	-53.21
Armenia	4.75	5.04	5.73	6.90	3.73	3.30	4.28	5.17	4.38	4.12	4.92	5.72	89.79
Australia	-3.85	-4.68	-4.78	-9.65	-4.08	-4.38	-4.15	-10.54	-4.53	-6.06	-6.86	-13.55	-52.87
Austria	7.48	12.00	14.71	19.80	8.14	14.16	17.02	23.65	7.25	11.63	14.20	18.16	102.53
Azerbaijan	-0.67	-6.77	-8.00	-9.91	-0.45	-6.09	-7.22	-9.09	-1.02	-7.23	-8.47	-10.47	-23.72
Burundi	-7.70	-12.84	-15.31	-23.31	-7.61	-12.34	-14.89	-22.47	-8.00	-13.17	-15.66	-23.75	-79.29
Belgium	-4.31	-7.73	-3.53	0.76	-5.13	-8.79	-4.14	-0.12	-4.73	-8.34	-3.86	0.48	29.85
Benin	-2.61	-2.42	-5.86	-11.84	-3.02	-3.34	-7.20	-13.33	-2.69	-2.53	-6.03	-12.12	-91.31
Burkina Faso	-0.87	-1.89	-2.30	-7.77	-0.70	-2.11	-2.27	-8.18	-1.00	-2.07	-2.50	-8.02	-86.88
Bangladesh	-10.45	-16.60	-16.31	-24.52	-10.07	-16.51	-16.12	-24.84	-10.68	-16.81	-16.58	-24.87	-89.81
Bulgaria	2.50	2.81	2.87	-5.85	3.36	4.24	4.85	-3.38	2.29	2.44	2.45	-6.59	29.55
Bosnia and Herzegovina	4.40	7.15	9.98	7.89	4.36	6.92	9.20	7.68	4.12	6.76	9.50	7.43	44.29
Belarus	15.01	21.25	22.94	25.73	15.21	21.06	22.65	25.30	13.91	19.99	21.61	23.92	170.25
Belize	-8.96	-9.62	-9.97	-14.70	-7.98	-9.37	-9.35	-14.59	-9.05	-9.87	-10.28	-15.02	-90.45
Bolivia	-6.99	-7.81	-10.63	-15.81	0.38	1.59	0.01	-3.54	-7.62	-8.82	-12.18	-20.17	-69.14
Brazil	-7.94	-9.71	-12.41	-19.88	-8.38	-9.58	-12.19	-20.83	-8.17	-9.99	-12.70	-20.62	-82.77
Brunei	2.28	2.27	-3.06	-14.54	2.88	3.17	-2.43	-14.86	2.27	2.25	-3.08	-14.58	-87.83
Bhutan	0.60	2.27	1.46	3.07	2.41	4.03	2.75	3.41	0.25	1.28	0.21	-0.39	-16.05
Botswana	-4.53	-17.78	-17.04	-29.73	-1.75	-16.04	-14.55	-30.56	-4.83	-17.95	-17.22	-29.90	-89.61

Central African Republic	-4.28	-4.40	-7.10	-13.19	-3.61	-3.72	-6.66	-12.98	-4.33	-4.50	-7.20	-13.36	-90.77
Canada	21.84	37.07	44.11	64.73	11.58	20.04	24.01	32.57	19.48	32.20	38.19	53.54	246.69
Switzerland	7.42	17.99	20.94	28.02	6.29	18.18	21.42	30.19	7.33	17.82	20.72	27.35	120.91
Chile	6.95	10.84	13.20	20.16	7.43	10.81	13.02	14.08	6.31	9.40	11.19	15.27	31.96
China	0.78	0.48	0.88	1.34	0.21	-0.68	-0.42	-1.20	0.15	-0.68	-0.59	-1.58	-42.07
Ivory Coast	-5.49	-4.23	-7.95	-15.86	-5.82	-4.31	-7.72	-16.77	-5.62	-4.32	-8.05	-16.20	-90.71
Cameroon	-2.14	-1.05	-4.49	-9.51	-2.07	-1.50	-4.34	-8.49	-2.25	-1.31	-4.71	-9.80	-88.01
Republic of Congo	-0.93	0.80	-2.77	-9.40	-0.94	-0.09	-3.14	-10.36	-0.98	0.72	-2.83	-9.59	-88.69
Colombia	-3.96	-5.72	-8.56	-15.62	-3.38	-6.07	-8.05	-14.73	-4.30	-6.36	-9.28	-16.76	-77.33
Costa Rica	-4.12	-0.09	-3.78	-5.84	-3.59	0.95	-2.76	-2.10	-4.25	-0.50	-4.10	-6.67	-79.21
Cuba	-7.36	-10.79	-11.65	-16.74	-6.72	-10.56	-11.58	-16.43	-7.52	-10.92	-11.78	-16.95	-83.77
Czech Republic	14.73	19.83	22.21	28.60	14.34	19.25	21.44	26.88	14.26	19.17	21.42	27.12	101.69
Germany	7.84	8.90	9.34	12.72	7.19	8.67	9.30	13.13	7.47	8.38	8.73	11.84	62.69
Djibouti	0.41	-1.31	1.45	1.55	1.39	-0.35	2.66	1.46	0.34	-1.47	1.30	1.41	-84.51
Denmark	10.68	13.47	16.54	17.50	11.41	14.43	17.62	18.27	10.60	13.33	16.40	17.28	86.18
Dominican Republic	-9.69	-12.31	-13.04	-18.26	-9.64	-12.48	-13.19	-18.87	-9.76	-12.40	-13.16	-18.44	-85.61
Algeria	-5.81	-9.09	-10.59	-14.94	-6.97	-9.91	-11.93	-15.38	-6.35	-9.82	-11.53	-16.08	-67.35
Ecuador	-0.62	-1.70	-3.15	-8.99	0.07	-0.77	-1.76	-7.59	-1.15	-2.60	-4.40	-11.53	-69.25
Egypt	-7.62	-12.02	-13.86	-20.70	-9.40	-13.86	-15.79	-22.01	-7.76	-12.25	-14.14	-21.10	-84.07
Eritrea	-2.46	-6.60	-5.09	-8.37	-1.69	-7.03	-5.46	-10.33	-2.84	-7.36	-6.06	-10.24	-87.46
Spain	-2.64	-4.75	-4.68	-9.56	-2.23	-4.60	-4.49	-10.18	-3.06	-5.61	-5.83	-11.54	-46.36
Estonia	30.83	45.53	51.16	57.04	29.35	43.94	49.52	55.22	30.25	44.93	50.56	56.32	258.80
Ethiopia	-4.11	-8.02	-9.56	-15.62	-3.52	-7.99	-9.47	-16.89	-4.53	-8.61	-10.31	-16.86	-74.48
Finland	32.07	53.77	65.52	86.57	30.05	48.79	60.60	74.51	31.36	52.13	63.73	80.33	516.18
France	0.30	4.43	4.00	8.72	0.83	4.19	3.64	7.55	-0.06	3.84	3.46	8.11	9.63
Gabon	-1.81	0.89	-2.01	-7.99	-2.23	0.74	-2.41	-8.18	-1.83	0.84	-2.04	-8.07	-89.05
United Kingdom	3.49	3.94	6.11	8.01	2.11	1.95	3.65	5.19	3.15	3.43	5.42	7.29	41.79
Georgia	1.66	0.18	-0.27	-1.50	0.77	0.32	0.12	-1.34	1.42	-0.06	-0.56	-1.97	7.72
Ghana	-5.15	-5.07	-8.36	-14.56	-4.82	-4.94	-8.50	-15.90	-5.26	-5.22	-8.56	-15.13	-90.15
Guinea	-6.39	-7.26	-9.79	-14.03	-6.50	-7.26	-9.91	-14.04	-6.46	-7.35	-9.89	-14.20	-91.75
Gambia	-4.05	-6.56	-8.80	-15.21	-3.92	-6.22	-8.60	-16.16	-4.18	-6.84	-8.97	-15.51	-88.71

Guinea-Bissau	-1.80	-5.66	-7.07	-13.32	-1.84	-5.75	-7.18	-13.56	-1.84	-5.73	-7.13	-13.39	-89.26
Equatorial Guinea	-0.66	2.62	-0.32	-3.76	-0.65	2.18	-0.85	-4.94	-0.67	2.57	-0.34	-3.92	-84.51
Greece	-2.81	-4.74	-3.25	-8.19	-2.81	-5.07	-3.84	-9.09	-3.05	-5.04	-3.58	-8.65	-50.72
Guatemala	-7.95	-9.11	-9.42	-13.35	-7.26	-6.91	-7.67	-11.34	-8.09	-9.61	-9.84	-14.00	-83.34
French Guiana	-0.33	1.00	-1.91	-3.56	0.71	1.50	-1.22	-3.11	-0.43	0.93	-2.00	-3.70	
Guyana	-4.41	-7.93	-9.16	-16.37	-4.70	-8.77	-9.56	-17.52	-4.59	-8.23	-9.45	-16.83	-91.45
Hong Kong	-6.71	-9.17	-12.65	-18.09	-6.99	-9.49	-12.94	-18.48	-6.71	-9.18	-12.65	-18.10	
Honduras	-8.85	-10.51	-11.79	-16.22	-8.30	-10.87	-12.05	-17.01	-8.92	-10.60	-11.89	-16.34	-88.40
Croatia	4.18	6.44	8.95	4.15	3.55	6.26	9.23	3.88	3.86	5.98	8.19	3.70	-8.95
Haiti	-7.57	-10.80	-11.30	-16.64	-7.14	-10.28	-10.98	-16.12	-7.66	-10.91	-11.42	-16.94	-85.23
Hungary	7.52	10.77	13.39	6.37	7.80	11.04	13.50	6.92	7.38	10.65	13.24	6.20	25.17
Indonesia	-0.12	-1.62	-5.27	-15.26	-0.05	-1.90	-5.53	-16.45	-0.25	-1.79	-5.44	-15.62	-85.07
India	-5.81	-6.47	-11.28	-14.95	-6.28	-6.88	-11.94	-15.74	-6.23	-6.90	-11.78	-15.73	-91.83
Ireland	2.72	3.47	6.53	6.17	2.27	2.84	5.58	5.02	2.64	3.34	6.36	5.87	47.28
Iran	1.56	-1.33	-1.58	-3.29	1.50	-0.91	-0.89	-1.80	1.35	-1.68	-1.98	-3.99	-58.15
Iraq	-0.45	-4.01	-5.94	-11.65	-1.83	-5.53	-7.77	-12.86	-0.65	-4.36	-6.40	-12.37	-93.00
Iceland	27.24	44.50	52.63	75.17	13.47	28.21	32.63	48.25	25.23	41.84	49.51	70.41	512.92
Israel	-3.52	-11.00	-12.27	-23.93	-2.21	-10.05	-11.39	-23.73	-3.76	-11.15	-12.47	-24.09	-82.24
Italy	1.74	2.75	3.31	-0.90	2.14	3.70	4.31	0.33	1.42	2.18	2.69	-1.49	-25.86
Jordan	-2.88	-6.66	-7.01	-12.02	-2.96	-8.32	-9.14	-16.68	-2.99	-6.89	-7.32	-12.60	-72.27
Japan	6.03	8.18	12.84	18.15	6.00	6.99	10.96	14.60	5.40	6.92	11.29	15.94	-35.15
Kazakhstan	12.33	13.87	11.16	15.30	12.75	15.10	12.67	17.17	11.29	12.33	9.63	12.87	208.29
Kenya	-2.18	-4.95	-7.20	-14.68	-4.29	-7.59	-9.93	-17.55	-2.64	-5.58	-7.90	-15.72	-73.29
Kyrgyzstan	10.11	14.17	13.86	18.05	9.25	12.80	11.81	14.66	9.72	13.51	12.88	16.12	169.58
Cambodia	-6.84	-9.53	-12.13	-17.15	-7.34	-10.30	-12.99	-18.24	-6.91	-9.62	-12.25	-17.30	-86.25
South Korea	9.67	12.36	15.13	14.72	10.94	13.75	16.80	17.15	9.55	12.17	14.84	14.00	-0.26
Kuwait	-3.02	-7.12	-10.02	-14.25	-1.98	-6.56	-9.23	-13.53	-3.04	-7.13	-10.04	-14.26	-95.56
Laos	-7.01	-11.87	-10.85	-16.60	-7.40	-12.37	-11.19	-17.00	-7.09	-12.00	-10.96	-16.85	-86.15
Lebanon	-2.58	-5.79	-5.94	-11.42	-2.95	-5.89	-6.06	-11.14	-2.62	-5.88	-6.06	-11.79	-39.92
Liberia	-1.16	-1.76	-5.56	-10.31	-1.22	-1.63	-5.35	-10.51	-1.21	-1.82	-5.62	-10.51	-88.38
Libya	-6.38	-10.06	-12.04	-18.72	-6.25	-10.65	-13.85	-21.33	-6.55	-10.37	-12.38	-19.19	-83.52
Liechtenstein	4.36	25.61	30.44	55.25	4.36	25.61	30.44	55.25	4.36	25.61	30.44	55.25	
Sri Lanka	-4.85	-5.60	-7.25	-12.47	-4.96	-6.22	-7.29	-12.78	-5.03	-5.74	-7.42	-12.67	-85.70

Lesotho	4.65	4.90	7.66	1.67	4.76	5.33	7.81	-0.48	4.50	4.66	7.41	0.50	-2.41
Lithuania	26.99	34.41	36.42	42.54	26.11	33.23	35.60	41.47	26.83	34.15	36.24	42.23	156.57
Luxembourg	5.37	3.15	1.00	1.57	4.08	0.54	-1.02	-0.61	5.10	2.64	0.61	1.13	54.99
Latvia	28.57	38.83	42.40	47.57	26.80	36.67	40.06	44.73	28.06	38.17	41.82	46.57	190.08
Morocco	-8.31	-16.00	-18.14	-28.81	-8.38	-16.05	-18.42	-29.97	-8.54	-16.43	-18.84	-29.97	-66.98
Moldova	8.08	13.70	13.53	4.92	7.72	13.96	13.99	5.21	7.99	13.57	13.30	4.70	48.78
Madagascar	-5.04	-7.58	-9.41	-15.74	-3.75	-5.84	-7.30	-13.48	-5.27	-7.95	-9.88	-16.51	-73.39
Mexico	-4.25	-8.01	-9.14	-16.06	-4.65	-7.78	-9.17	-16.49	-4.68	-8.78	-9.99	-17.42	-73.41
Macedonia	2.08	2.78	5.13	-0.45	2.66	3.70	6.03	1.27	2.00	2.65	4.99	-0.72	35.55
Mali	-0.36	-1.94	-2.89	-9.99	-0.21	-1.33	-2.49	-9.65	-0.66	-2.39	-3.47	-10.75	-83.45
Myanmar	-8.99	-13.10	-11.89	-17.89	-8.15	-12.22	-10.78	-16.25	-9.27	-13.46	-12.35	-18.71	
Montenegro	-2.69	-1.85	-1.40	3.96	-0.26	1.81	2.00	7.39	-3.08	-2.68	-2.00	3.20	
Mongolia	17.91	24.77	27.38	36.50	21.78	31.44	35.86	48.41	17.23	23.78	25.77	33.95	1413.40
Mozambique	-6.17	-12.72	-15.51	-24.39	-5.78	-12.15	-14.96	-23.44	-6.29	-12.93	-15.74	-24.79	-89.30
Mauritania	-3.44	-8.15	-8.18	-16.19	0.75	-2.83	-1.33	-9.32	-3.89	-8.93	-9.29	-17.43	-80.44
Malawi	-4.44	-13.37	-15.95	-23.36	-4.39	-13.49	-16.11	-23.55	-4.50	-13.43	-16.02	-23.45	-87.06
Malaysia	0.10	-0.40	-3.55	-11.11	0.22	-0.03	-3.41	-12.52	0.04	-0.46	-3.63	-11.33	-87.44
Namibia	-7.49	-15.38	-15.75	-25.68	-5.68	-14.87	-14.59	-25.79	-7.69	-15.56	-15.92	-25.81	-88.74
Niger	5.07	4.42	5.62	-0.84	6.34	7.56	8.87	1.62	4.60	3.75	4.86	-1.92	-80.27
Nigeria	-2.61	-2.86	-5.74	-10.93	-2.40	-2.76	-5.39	-11.32	-2.75	-2.99	-5.92	-11.32	-91.49
Nicaragua	-7.38	-2.82	-6.61	-11.88	-7.13	-6.33	-8.91	-14.53	-7.47	-3.16	-6.83	-12.24	-91.55
Netherlands	0.85	-2.70	-1.61	6.10	1.28	-2.09	-1.53	6.09	0.60	-3.11	-1.89	5.88	30.88
Norway	17.81	34.97	42.19	53.33	13.20	25.37	32.41	33.81	16.79	32.39	39.36	45.59	249.29
Nepal	-5.57	-5.41	-7.36	-12.52	-4.92	-4.97	-6.66	-12.34	-5.91	-5.96	-8.18	-14.32	-85.26
New Zealand	6.15	9.93	16.32	22.77	5.68	10.75	17.43	22.32	5.79	9.41	15.57	21.16	-8.97
Oman	-7.97	-12.78	-13.16	-18.26	-5.15	-9.68	-10.68	-14.09	-8.07	-12.93	-13.33	-18.51	-94.38
Pakistan	-2.35	-6.86	-6.84	-10.62	-2.89	-7.66	-7.32	-11.36	-2.74	-7.53	-7.52	-11.47	-92.55
Panama	-3.00	-0.74	-3.72	-6.10	-2.28	0.52	-2.77	-5.67	-3.06	-0.83	-3.82	-6.39	-85.41
Peru	-0.78	-1.26	-3.06	-6.20	1.11	1.36	1.28	0.35	-1.68	-3.08	-5.48	-11.40	-50.66
Philippines	-3.63	-4.79	-8.49	-14.44	-4.32	-5.57	-9.38	-15.68	-3.70	-4.91	-8.61	-14.69	-83.57
Papua New Guinea	-2.62	-4.74	-9.86	-18.99	-3.45	-6.17	-10.07	-19.90	-2.76	-4.92	-10.08	-19.36	-74.92
Poland	12.44	15.70	16.62	16.72	14.00	17.43	18.58	18.88	12.04	15.23	16.01	15.75	87.90
North Korea	9.60	14.31	15.20	19.90	10.36	16.26	16.83	22.60	9.48	13.85	14.88	18.87	

Portugal	-7.09	-9.44	-9.59	-16.14	-5.56	-7.13	-7.15	-13.04	-7.52	-9.97	-10.16	-17.14	-41.02
Paraguay	-11.26	-12.84	-17.52	-32.82	-8.30	-9.57	-15.23	-30.55	-11.75	-13.34	-18.08	-33.56	-84.18
Palestine	-4.59	-9.75	-10.80	-20.17	-4.02	-9.00	-9.93	-19.23	-4.64	-9.81	-10.90	-20.25	
Qatar	-6.23	-9.34	-11.82	-17.11	-6.43	-9.65	-12.03	-17.49	-6.24	-9.35	-11.83	-17.12	-91.60
Romania	5.77	6.26	7.35	1.27	6.57	7.64	8.53	2.82	5.50	5.73	6.71	0.10	49.57
Russia	22.97	34.14	38.44	52.65	21.32	29.02	31.52	38.32	20.08	27.78	30.49	37.57	419.15
Rwanda	-7.60	-12.84	-15.65	-22.59	-6.70	-12.41	-15.34	-22.29	-8.57	-13.63	-16.56	-23.23	-78.35
Saudi Arabia	-3.76	-7.89	-8.30	-14.18	-2.34	-6.85	-7.05	-12.74	-3.99	-8.19	-8.63	-14.49	-95.74
Sudan	-2.20	-2.84	-2.18	-7.68	-1.26	-2.80	-0.93	-6.70	-2.36	-3.07	-2.52	-8.13	-86.80
Senegal	-3.16	-6.03	-6.80	-13.18	-4.82	-8.50	-9.45	-15.65	-3.34	-6.36	-7.17	-13.68	-89.13
Singapore	1.36	3.75	0.10	-10.39	1.36	3.75	0.10	-10.39	1.36	3.75	0.10	-10.39	
Sierra Leone	-8.02	-9.57	-12.60	-15.64	-8.01	-9.45	-12.58	-15.70	-8.07	-9.62	-12.65	-15.69	-91.00
El Salvador	-5.95	-6.89	-8.47	-12.83	-5.85	-6.33	-7.78	-12.69	-5.97	-6.93	-8.52	-12.89	-85.40
Somalia	-4.26	-8.88	-7.98	-10.11	-3.29	-7.73	-6.85	-9.15	-4.49	-9.23	-8.39	-11.02	
Serbia	5.74	8.00	11.66	2.29	5.45	7.77	11.38	2.61	5.61	7.84	11.47	1.84	30.70
Suriname	-2.69	-4.39	-7.60	-10.95	-4.29	-7.07	-10.00	-14.05	-2.84	-4.56	-7.74	-11.22	-92.19
Slovakia	9.55	14.04	14.73	16.29	11.34	16.01	17.36	20.06	9.30	13.69	14.22	15.13	90.78
Slovenia	3.12	9.63	12.52	13.75	2.65	10.51	13.27	15.32	3.05	9.49	12.36	13.26	79.85
Sweden	19.10	33.06	39.72	50.41	19.46	32.87	39.29	45.99	18.73	31.94	37.83	45.08	210.20
Swaziland	-4.51	-11.10	-11.46	-21.54	-5.10	-11.30	-11.86	-21.55	-4.99	-11.49	-11.95	-21.86	-77.62
Syria	-4.49	-7.37	-7.12	-10.47	-4.83	-8.13	-7.33	-10.70	-4.67	-7.62	-7.40	-10.86	-71.71
Chad	1.29	1.31	1.64	-4.45	0.45	0.57	0.84	-5.20	1.05	1.08	1.34	-4.77	-86.43
Togo	-2.61	-3.06	-7.15	-11.74	-2.19	-2.70	-6.48	-11.26	-2.66	-3.15	-7.32	-12.05	-89.66
Thailand	-8.50	-11.36	-12.29	-17.03	-8.84	-11.40	-12.96	-17.42	-8.59	-11.56	-12.42	-17.21	-90.00
Tajikistan	3.51	5.27	6.59	9.10	2.82	4.36	5.39	7.50	3.24	4.76	6.02	8.00	-14.84
Turkmenistan	-3.82	-6.23	-8.00	-10.61	-3.59	-5.83	-7.42	-10.11	-3.93	-6.49	-8.28	-10.92	-60.31
Timor-Leste	-3.97	-6.51	-7.68	-13.08	-3.88	-6.61	-7.95	-13.14	-3.98	-6.54	-7.71	-13.18	
Trinidad and Tobago	-9.03	-8.55	-12.10	-20.10	-9.39	-8.73	-12.32	-19.66	-9.08	-8.67	-12.29	-20.44	-81.73
Tunisia	-4.02	-6.15	-8.34	-11.85	-4.66	-6.94	-9.35	-12.79	-4.40	-6.63	-8.92	-12.51	-76.34
Turkey	-0.84	-2.85	-1.72	-6.28	-1.47	-3.08	-1.93	-5.84	-1.01	-3.12	-2.01	-6.93	-16.62
Taiwan	-0.90	-4.41	-5.36	-8.35	-0.75	-4.62	-5.22	-8.68	-1.33	-4.96	-5.95	-9.39	
Tanzania	-4.66	-9.10	-11.85	-18.89	-3.92	-7.90	-10.65	-17.53	-4.84	-9.37	-12.14	-19.23	-83.83

Uganda	-6.33	-5.39	-9.20	-14.08	-6.69	-5.91	-9.62	-14.71	-6.76	-6.10	-9.90	-14.88	-83.14
Ukraine	9.93	11.84	13.71	9.76	10.90	12.73	14.62	11.01	9.61	11.33	13.23	8.90	81.51
Uruguay	-13.28	-18.44	-18.89	-24.71	-11.71	-17.79	-17.57	-24.04	-13.74	-19.12	-19.40	-25.10	-54.70
United States	1.38	2.23	2.81	4.81	-0.03	0.68	0.69	0.04	0.50	0.61	0.53	0.23	-36.28
Uzbekistan	-0.55	0.01	-0.50	-0.80	0.46	1.64	1.31	1.60	-0.70	-0.19	-0.78	-1.20	-45.49
Venezuela	-7.02	-8.96	-11.76	-19.47	-7.71	-9.79	-12.13	-20.89	-7.14	-9.28	-12.11	-20.34	-90.96
Vietnam	-6.42	-9.54	-10.29	-16.41	-6.88	-10.55	-11.26	-18.18	-6.52	-9.84	-10.47	-16.77	-87.50
Yemen	-6.44	-11.47	-10.76	-15.58	-2.98	-7.33	-6.19	-10.87	-6.72	-11.86	-11.24	-16.33	-87.96
South Africa	-2.15	-8.90	-8.94	-21.00	-3.64	-11.55	-11.65	-23.78	-2.91	-9.94	-10.33	-22.30	-66.19
Democratic Republic of the Congo	-3.55	-4.06	-7.89	-16.65	-4.43	-5.27	-9.00	-17.80	-3.73	-4.39	-8.20	-16.99	-87.92
Zambia	-7.91	-14.46	-16.95	-25.44	-7.49	-14.29	-16.86	-25.52	-7.98	-14.52	-17.00	-25.50	-86.80
Zimbabwe	-9.23	-19.26	-20.84	-31.89	-9.34	-19.53	-21.26	-32.05	-9.58	-19.69	-21.27	-32.37	-83.83

Table C3: Decomposition of Terms: Climate Change Only

	X Term	Distribution Term		Offset Term		
		Immobile, Hist.	Immobile, Efficient	Mobile	Immobile, Hist.	Immobile, Efficient
Afghanistan	0.973	1.015	0.990	1.002	1.000	1.002
Angola	0.775	1.033	0.994	1.013	1.012	1.014
Albania	1.006	1.007	0.999	1.000	0.999	1.000
United Arab Emirates	0.869	0.978	0.998	1.009	1.010	1.009
Argentina	0.916	0.947	0.976	1.006	1.008	1.006
Armenia	1.074	0.983	0.989	0.995	0.996	0.996
Australia	0.898	0.991	0.955	1.007	1.006	1.008
Austria	1.213	1.035	0.986	0.988	0.985	0.988
Azerbaijan	0.894	1.010	0.994	1.007	1.006	1.008
Burundi	0.755	1.012	0.994	1.015	1.015	1.016
Belgium	1.008	0.991	0.997	0.999	1.000	1.000
Benin	0.875	0.982	0.997	1.007	1.008	1.007
Burkina Faso	0.918	0.995	0.997	1.005	1.005	1.005
Bangladesh	0.740	0.996	0.995	1.020	1.021	1.021
Bulgaria	0.937	1.029	0.992	1.005	1.002	1.005
Bosnia and Herzegovina	1.085	0.998	0.996	0.994	0.994	0.994
Belarus	1.278	0.997	0.985	0.984	0.984	0.984
Belize	0.844	1.001	0.996	1.010	1.010	1.011
Bolivia	0.832	1.160	0.946	1.011	0.999	1.014
Brazil	0.788	0.988	0.991	1.016	1.017	1.017
Brunei	0.845	0.996	0.999	1.011	1.012	1.011
Bhutan	1.033	1.006	0.965	0.998	0.995	0.999
Botswana	0.687	0.987	0.997	1.023	1.024	1.024
Central African Republic	0.860	1.003	0.998	1.009	1.009	1.009
Canada	1.699	0.796	0.930	0.969	0.981	0.971
Switzerland	1.301	1.018	0.995	0.984	0.983	0.984
Chile	1.217	0.948	0.958	0.988	0.989	0.989
China	1.014	0.974	0.970	0.999	1.000	1.000
Ivory Coast	0.833	0.989	0.996	1.010	1.011	1.010
Cameroon	0.900	1.012	0.997	1.006	1.005	1.006
Republic of Congo	0.901	0.989	0.998	1.006	1.006	1.006
Colombia	0.834	1.012	0.986	1.012	1.011	1.013

Costa Rica	0.938	1.043	0.991	1.004	1.001	1.005
Cuba	0.821	1.004	0.997	1.014	1.014	1.014
Czech Republic	1.308	0.986	0.988	0.983	0.983	0.983
Germany	1.137	1.004	0.992	0.992	0.991	0.992
Djibouti	1.017	0.999	0.999	0.999	0.999	0.999
Denmark	1.188	1.007	0.998	0.989	0.989	0.989
Dominican Republic	0.806	0.992	0.998	1.014	1.015	1.014
Algeria	0.842	0.995	0.986	1.011	1.010	1.011
Ecuador	0.904	1.018	0.971	1.006	1.004	1.007
Egypt	0.781	0.983	0.995	1.015	1.016	1.015
Eritrea	0.911	0.978	0.979	1.005	1.006	1.006
Spain	0.898	0.994	0.977	1.008	1.007	1.008
Estonia	1.621	0.988	0.995	0.968	0.969	0.969
Ethiopia	0.835	0.984	0.985	1.010	1.011	1.011
Finland	1.944	0.932	0.965	0.960	0.963	0.961
France	1.094	0.989	0.994	0.994	0.995	0.994
Gabon	0.916	0.998	0.999	1.005	1.005	1.005
United Kingdom	1.086	0.972	0.993	0.995	0.996	0.995
Georgia	0.984	1.002	0.995	1.001	1.001	1.001
Ghana	0.846	0.984	0.993	1.010	1.010	1.010
Guinea	0.852	1.000	0.998	1.009	1.009	1.009
Gambia	0.840	0.988	0.996	1.010	1.010	1.010
Guinea-Bissau	0.859	0.997	0.999	1.009	1.009	1.009
Equatorial Guinea	0.960	0.987	0.998	1.002	1.003	1.002
Greece	0.912	0.990	0.995	1.007	1.007	1.007
Guatemala	0.859	1.025	0.992	1.009	1.007	1.009
French Guiana	0.962	1.005	0.999	1.002	1.002	1.002
Guyana	0.825	0.985	0.994	1.014	1.014	1.014
Hong Kong	0.808	0.995	1.000	1.014	1.015	1.014
Honduras	0.828	0.990	0.999	1.012	1.012	1.012
Croatia	1.045	0.997	0.996	0.997	0.997	0.997
Haiti	0.823	1.007	0.996	1.012	1.012	1.012
Hungary	1.069	1.006	0.998	0.995	0.995	0.996
Indonesia	0.838	0.985	0.996	1.011	1.012	1.012
India	0.841	0.990	0.990	1.011	1.012	1.012
Ireland	1.066	0.989	0.997	0.996	0.997	0.996
Iran	0.965	1.017	0.993	1.002	1.001	1.002
Iraq	0.877	0.986	0.992	1.007	1.008	1.008
Iceland	1.817	0.838	0.972	0.964	0.973	0.965

Israel	0.748	1.003	0.998	1.018	1.017	1.018
Italy	0.990	1.014	0.994	1.001	0.999	1.001
Jordan	0.873	0.944	0.993	1.008	1.012	1.009
Japan	1.196	0.968	0.981	0.988	0.989	0.988
Kazakhstan	1.164	1.018	0.978	0.991	0.989	0.992
Kenya	0.845	0.965	0.987	1.010	1.011	1.010
Kyrgyzstan	1.193	0.970	0.983	0.990	0.991	0.990
Cambodia	0.818	0.986	0.998	1.013	1.014	1.013
South Korea	1.159	1.023	0.994	0.990	0.988	0.990
Kuwait	0.849	1.009	1.000	1.010	1.009	1.010
Laos	0.824	0.995	0.997	1.013	1.013	1.013
Lebanon	0.878	1.003	0.996	1.008	1.008	1.009
Liberia	0.891	0.998	0.998	1.006	1.007	1.007
Libya	0.801	0.966	0.994	1.014	1.017	1.015
Liechtenstein	1.597	1.000	1.000	0.972	0.972	0.972
Sri Lanka	0.867	0.996	0.998	1.010	1.010	1.010
Lesotho	1.018	0.978	0.988	0.999	1.000	0.999
Lithuania	1.463	0.992	0.998	0.974	0.974	0.974
Luxembourg	1.017	0.977	0.996	0.999	1.000	0.999
Latvia	1.518	0.980	0.993	0.972	0.973	0.972
Morocco	0.695	0.983	0.983	1.024	1.024	1.025
Moldova	1.053	1.003	0.998	0.996	0.996	0.996
Madagascar	0.834	1.029	0.991	1.010	1.008	1.010
Mexico	0.829	0.995	0.983	1.012	1.012	1.013
Macedonia	0.995	1.019	0.997	1.000	0.999	1.000
Mali	0.895	1.004	0.991	1.006	1.006	1.006
Myanmar	0.810	1.022	0.990	1.014	1.012	1.014
Montenegro	1.043	1.036	0.992	0.997	0.995	0.997
Mongolia	1.392	1.093	0.981	0.981	0.976	0.981
Mozambique	0.744	1.013	0.995	1.016	1.016	1.017
Mauritania	0.830	1.087	0.985	1.010	1.005	1.011
Malawi	0.754	0.997	0.999	1.016	1.016	1.016
Malaysia	0.882	0.983	0.997	1.008	1.009	1.008
Namibia	0.729	0.998	0.998	1.019	1.019	1.019
Niger	0.991	1.026	0.989	1.000	0.999	1.001
Nigeria	0.885	0.996	0.996	1.007	1.007	1.007
Nicaragua	0.874	0.968	0.996	1.009	1.011	1.009
Netherlands	1.065	1.000	0.998	0.996	0.996	0.996
Norway	1.575	0.867	0.948	0.974	0.980	0.975
Nepal	0.866	1.003	0.979	1.010	1.009	1.011

New Zealand	1.244	0.997	0.987	0.987	0.986	0.987
Oman	0.807	1.055	0.997	1.013	1.010	1.013
Pakistan	0.887	0.991	0.990	1.007	1.007	1.007
Panama	0.935	1.005	0.997	1.004	1.004	1.004
Peru	0.934	1.078	0.942	1.004	0.997	1.007
Philippines	0.847	0.985	0.997	1.010	1.011	1.011
Papua New Guinea	0.800	0.988	0.995	1.013	1.014	1.013
Poland	1.181	1.020	0.991	0.989	0.987	0.989
North Korea	1.214	1.025	0.991	0.988	0.986	0.988
Portugal	0.827	1.040	0.988	1.013	1.010	1.014
Paraguay	0.653	1.037	0.989	1.028	1.025	1.029
Palestine	0.787	1.013	0.999	1.014	1.013	1.014
Qatar	0.819	0.995	1.000	1.012	1.012	1.012
Romania	1.014	1.017	0.988	0.999	0.997	0.999
Russia	1.571	0.902	0.898	0.972	0.976	0.975
Rwanda	0.762	1.004	0.991	1.016	1.015	1.016
Saudi Arabia	0.849	1.018	0.996	1.010	1.009	1.010
Sudan	0.919	1.011	0.995	1.005	1.004	1.005
Senegal	0.861	0.970	0.994	1.008	1.010	1.008
Singapore	0.889	1.000	1.000	1.008	1.008	1.008
Sierra Leone	0.835	0.999	0.999	1.011	1.011	1.011
El Salvador	0.863	1.002	0.999	1.010	1.010	1.010
Somalia	0.894	1.012	0.990	1.006	1.005	1.006
Serbia	1.025	1.004	0.995	0.998	0.998	0.998
Suriname	0.883	0.963	0.997	1.008	1.010	1.008
Slovakia	1.176	1.035	0.990	0.989	0.986	0.990
Slovenia	1.148	1.015	0.996	0.991	0.990	0.991
Sweden	1.544	0.970	0.963	0.974	0.975	0.975
Swaziland	0.772	1.000	0.996	1.016	1.016	1.016
Syria	0.889	0.997	0.995	1.007	1.007	1.007
Chad	0.953	0.992	0.997	1.003	1.003	1.003
Togo	0.876	1.006	0.996	1.007	1.007	1.007
Thailand	0.818	0.995	0.998	1.014	1.014	1.014
Tajikistan	1.097	0.985	0.990	0.995	0.996	0.995
Turkmenistan	0.887	1.006	0.996	1.007	1.007	1.008
Timor-Leste	0.861	0.999	0.999	1.009	1.009	1.009
Trinidad and Tobago	0.786	1.006	0.996	1.017	1.016	1.017
Tunisia	0.874	0.989	0.992	1.009	1.009	1.009
Turkey	0.933	1.005	0.993	1.004	1.004	1.005

Taiwan	0.911	0.997	0.988	1.007	1.006	1.007
Tanzania	0.802	1.018	0.996	1.012	1.011	1.012
Uganda	0.852	0.992	0.991	1.009	1.009	1.009
Ukraine	1.105	1.013	0.992	0.993	0.992	0.993
Uruguay	0.738	1.010	0.995	1.021	1.020	1.021
United States	1.051	0.952	0.955	0.997	0.999	0.999
Uzbekistan	0.992	1.026	0.996	1.001	0.999	1.001
Venezuela	0.793	0.982	0.989	1.015	1.016	1.016
Vietnam	0.825	0.977	0.996	1.013	1.014	1.013
Yemen	0.835	1.060	0.991	1.011	1.007	1.011
South Africa	0.778	0.963	0.983	1.016	1.018	1.017
Democratic Republic of the Congo	0.825	0.986	0.996	1.010	1.011	1.011
Zambia	0.733	0.999	0.999	1.017	1.017	1.017
Zimbabwe	0.664	0.998	0.993	1.025	1.025	1.025

Table C4: Decomposition of Terms: Climate Change and Population Growth

	L Term	X Term	Distribution Term		Offset Term		
			Immobile, Hist.	Immobile, Efficient	Mobile	Immobile, Hist.	Immobile, Efficient
Afghanistan	0.730	0.973	1.015	0.990	0.964	0.962	0.964
Angola	0.499	0.775	1.033	0.994	0.935	0.933	0.935
Albania	1.394	1.006	1.007	0.999	1.047	1.047	1.047
United Arab Emirates	0.872	0.869	0.978	0.998	0.991	0.993	0.991
Argentina	0.896	0.916	0.947	0.976	0.992	0.994	0.992
Armenia	1.122	1.074	0.983	0.989	1.011	1.011	1.011
Australia	0.802	0.898	0.991	0.955	0.979	0.979	0.981
Austria	0.990	1.213	1.035	0.986	0.986	0.983	0.987
Azerbaijan	0.994	0.894	1.010	0.994	1.007	1.006	1.007
Burundi	0.554	0.755	1.012	0.994	0.947	0.947	0.947
Belgium	0.957	1.008	0.991	0.997	0.994	0.994	0.994
Benin	0.580	0.875	0.982	0.997	0.944	0.945	0.944
Burkina Faso	0.572	0.918	0.995	0.997	0.941	0.941	0.941
Bangladesh	0.992	0.740	0.996	0.995	1.019	1.019	1.019
Bulgaria	1.274	0.937	1.029	0.992	1.039	1.036	1.039

Bosnia and Herzegovina	1.312	1.085	0.998	0.996	1.032	1.032	1.032
Belarus	1.082	1.278	0.997	0.985	0.994	0.994	0.995
Belize	0.804	0.844	1.001	0.996	0.983	0.983	0.983
Bolivia	0.833	0.832	1.160	0.946	0.988	0.976	0.990
Brazil	1.027	0.788	0.988	0.991	1.020	1.020	1.020
Brunei	0.999	0.845	0.996	0.999	1.011	1.011	1.011
Bhutan	1.000	1.033	1.006	0.965	0.998	0.995	0.999
Botswana	0.781	0.687	0.987	0.997	0.992	0.993	0.993
Central African Republic	0.722	0.860	1.003	0.998	0.969	0.969	0.969
Canada	0.843	1.699	0.796	0.930	0.949	0.960	0.951
Switzerland	0.891	1.301	1.018	0.995	0.970	0.968	0.970
Chile	0.995	1.217	0.948	0.958	0.987	0.989	0.988
China	1.087	1.014	0.974	0.970	1.010	1.011	1.011
Ivory Coast	0.597	0.833	0.989	0.996	0.950	0.950	0.950
Cameroon	0.609	0.900	1.012	0.997	0.948	0.947	0.948
Republic of Congo	0.589	0.901	0.989	0.998	0.944	0.945	0.944
Colombia	1.000	0.834	1.012	0.986	1.012	1.011	1.013
Costa Rica	0.984	0.938	1.043	0.991	1.002	0.999	1.002
Cuba	1.189	0.821	1.004	0.997	1.038	1.038	1.038
Czech Republic	1.008	1.308	0.986	0.988	0.984	0.985	0.984
Germany	1.026	1.137	1.004	0.992	0.995	0.994	0.995
Djibouti	0.858	1.017	0.999	0.999	0.980	0.980	0.980
Denmark	0.931	1.188	1.007	0.998	0.980	0.980	0.980
Dominican Republic	0.958	0.806	0.992	0.998	1.009	1.009	1.009
Algeria	0.798	0.842	0.995	0.986	0.982	0.982	0.983
Ecuador	0.850	0.904	1.018	0.971	0.986	0.983	0.987
Egypt	0.717	0.781	0.983	0.995	0.974	0.975	0.974
Eritrea	0.705	0.911	0.978	0.979	0.963	0.964	0.964
Spain	1.122	0.898	0.994	0.977	1.023	1.023	1.024
Estonia	1.167	1.621	0.988	0.995	0.989	0.989	0.989
Ethiopia	0.668	0.835	0.984	0.985	0.962	0.963	0.962
Finland	1.007	1.944	0.932	0.965	0.961	0.964	0.962
France	0.986	1.094	0.989	0.994	0.992	0.993	0.993
Gabon	0.652	0.916	0.998	0.999	0.954	0.954	0.954
United Kingdom	0.933	1.086	0.972	0.993	0.986	0.988	0.986
Georgia	1.177	0.984	1.002	0.995	1.023	1.023	1.024

Ghana	0.679	0.846	0.984	0.993	0.963	0.964	0.963
Guinea	0.608	0.852	1.000	0.998	0.951	0.951	0.951
Gambia	0.603	0.840	0.988	0.996	0.951	0.951	0.951
Guinea-Bissau	0.644	0.859	0.997	0.999	0.956	0.957	0.956
Equatorial Guinea	0.594	0.960	0.987	0.998	0.942	0.943	0.942
Greece	1.183	0.912	0.990	0.995	1.030	1.030	1.030
Guatemala	0.776	0.859	1.025	0.992	0.978	0.976	0.978
French Guiana	0.631	0.962	1.005	0.999	0.948	0.948	0.948
Guyana	1.122	0.825	0.985	0.994	1.029	1.030	1.029
Hong Kong	0.969	0.808	0.995	1.000	1.010	1.010	1.010
Honduras	0.834	0.828	0.990	0.999	0.989	0.989	0.989
Croatia	1.256	1.045	0.997	0.996	1.029	1.029	1.029
Haiti	0.877	0.823	1.007	0.996	0.996	0.995	0.996
Hungary	1.131	1.069	1.006	0.998	1.012	1.012	1.012
Indonesia	0.910	0.838	0.985	0.996	0.999	1.000	0.999
India	0.948	0.841	0.990	0.990	1.004	1.005	1.005
Ireland	0.929	1.066	0.989	0.997	0.987	0.987	0.987
Iran	0.908	0.965	1.017	0.993	0.990	0.989	0.990
Iraq	0.651	0.877	0.986	0.992	0.957	0.957	0.957
Iceland	0.968	1.817	0.838	0.972	0.960	0.969	0.961
Israel	0.740	0.748	1.003	0.998	0.980	0.980	0.981
Italy	1.140	0.990	1.014	0.994	1.018	1.017	1.019
Jordan	0.810	0.873	0.944	0.993	0.982	0.986	0.982
Japan	1.197	1.196	0.968	0.981	1.012	1.014	1.013
Kazakhstan	0.835	1.164	1.018	0.978	0.969	0.967	0.969
Kenya	0.695	0.845	0.965	0.987	0.966	0.967	0.966
Kyrgyzstan	0.790	1.193	0.970	0.983	0.961	0.962	0.961
Cambodia	0.875	0.818	0.986	0.998	0.996	0.997	0.996
South Korea	1.188	1.159	1.023	0.994	1.013	1.011	1.013
Kuwait	0.785	0.849	1.009	1.000	0.980	0.979	0.980
Laos	0.905	0.824	0.995	0.997	1.000	1.000	1.000
Lebanon	0.954	0.878	1.003	0.996	1.002	1.002	1.002
Liberia	0.631	0.891	0.998	0.998	0.952	0.952	0.952
Libya	0.918	0.801	0.966	0.994	1.003	1.005	1.004
Liechtenstein	0.927	1.597	1.000	1.000	0.962	0.962	0.962
Sri Lanka	1.099	0.867	0.996	0.998	1.023	1.023	1.023
Lesotho	0.905	1.018	0.978	0.988	0.986	0.987	0.987
Lithuania	1.270	1.463	0.992	0.998	1.006	1.007	1.007
Luxembourg	0.802	1.017	0.977	0.996	0.972	0.973	0.972

Latvia	1.239	1.518	0.980	0.993	1.001	1.002	1.001
Morocco	0.898	0.695	0.983	0.983	1.010	1.010	1.010
Moldova	1.266	1.053	1.003	0.998	1.029	1.029	1.029
Madagascar	0.596	0.834	1.029	0.991	0.950	0.948	0.950
Mexico	0.931	0.829	0.995	0.983	1.003	1.003	1.003
Macedonia	1.183	0.995	1.019	0.997	1.023	1.022	1.023
Mali	0.572	0.895	1.004	0.991	0.942	0.941	0.942
Myanmar	0.971	0.810	1.022	0.990	1.010	1.008	1.010
Montenegro	1.112	1.043	1.036	0.992	1.011	1.009	1.012
Mongolia	0.796	1.392	1.093	0.981	0.953	0.948	0.954
Mozambique	0.575	0.744	1.013	0.995	0.952	0.951	0.952
Mauritania	0.589	0.830	1.087	0.985	0.949	0.944	0.949
Malawi	0.602	0.754	0.997	0.999	0.956	0.956	0.956
Malaysia	0.890	0.882	0.983	0.997	0.993	0.994	0.993
Namibia	0.733	0.729	0.998	0.998	0.981	0.981	0.981
Niger	0.464	0.991	1.026	0.989	0.916	0.915	0.917
Nigeria	0.600	0.885	0.996	0.996	0.947	0.947	0.947
Nicaragua	0.895	0.874	0.968	0.996	0.994	0.996	0.995
Netherlands	1.019	1.065	1.000	0.998	0.998	0.998	0.998
Norway	0.850	1.575	0.867	0.948	0.954	0.960	0.955
Nepal	1.044	0.866	1.003	0.979	1.016	1.014	1.016
New Zealand	0.899	1.244	0.997	0.987	0.973	0.973	0.974
Oman	0.748	0.807	1.055	0.997	0.977	0.974	0.977
Pakistan	0.764	0.887	0.991	0.990	0.974	0.974	0.974
Panama	0.827	0.935	1.005	0.997	0.980	0.980	0.980
Peru	0.905	0.934	1.078	0.942	0.992	0.984	0.994
Philippines	0.863	0.847	0.985	0.997	0.992	0.993	0.992
Papua New Guinea	0.718	0.800	0.988	0.995	0.973	0.973	0.973
Poland	1.185	1.181	1.020	0.991	1.012	1.010	1.012
North Korea	1.025	1.214	1.025	0.991	0.991	0.989	0.991
Portugal	1.149	0.827	1.040	0.988	1.033	1.029	1.033
Paraguay	0.894	0.653	1.037	0.989	1.014	1.011	1.014
Palestine	0.691	0.787	1.013	0.999	0.969	0.969	0.969
Qatar	0.764	0.819	0.995	1.000	0.979	0.979	0.979
Romania	1.199	1.014	1.017	0.988	1.024	1.022	1.024
Russia	1.044	1.571	0.902	0.898	0.977	0.981	0.980
Rwanda	0.670	0.762	1.004	0.991	0.968	0.967	0.968
Saudi Arabia	0.866	0.849	1.018	0.996	0.992	0.991	0.992
Sudan	0.624	0.919	1.011	0.995	0.949	0.949	0.950

Senegal	0.584	0.861	0.970	0.994	0.946	0.947	0.946
Singapore	0.964	0.889	1.000	1.000	1.003	1.003	1.003
Sierra Leone	0.727	0.835	0.999	0.999	0.972	0.972	0.972
El Salvador	1.091	0.863	1.002	0.999	1.022	1.022	1.022
Somalia	0.542	0.894	1.012	0.990	0.936	0.935	0.937
Serbia	1.287	1.025	1.004	0.995	1.034	1.033	1.034
Suriname	0.952	0.883	0.963	0.997	1.002	1.004	1.002
Slovakia	1.122	1.176	1.035	0.990	1.004	1.002	1.005
Slovenia	1.068	1.148	1.015	0.996	1.000	0.998	1.000
Sweden	0.897	1.544	0.970	0.963	0.961	0.962	0.962
Swaziland	0.792	0.772	1.000	0.996	0.987	0.987	0.987
Syria	0.840	0.889	0.997	0.995	0.985	0.985	0.985
Chad	0.578	0.953	0.992	0.997	0.940	0.940	0.940
Togo	0.620	0.876	1.006	0.996	0.951	0.951	0.951
Thailand	1.135	0.818	0.995	0.998	1.032	1.032	1.032
Tajikistan	0.667	1.097	0.985	0.990	0.947	0.948	0.948
Turkmenistan	0.845	0.887	1.006	0.996	0.986	0.986	0.986
Timor-Leste	0.772	0.861	0.999	0.999	0.977	0.977	0.977
Trinidad and Tobago	1.111	0.786	1.006	0.996	1.031	1.031	1.032
Tunisia	0.936	0.874	0.989	0.992	1.000	1.001	1.000
Turkey	0.943	0.933	1.005	0.993	0.997	0.996	0.997
Taiwan	1.126	0.911	0.997	0.988	1.023	1.022	1.023
Tanzania	0.537	0.802	1.018	0.996	0.941	0.940	0.941
Uganda	0.619	0.852	0.992	0.991	0.953	0.953	0.953
Ukraine	1.233	1.105	1.013	0.992	1.022	1.021	1.022
Uruguay	1.018	0.738	1.010	0.995	1.023	1.022	1.024
United States	0.893	1.051	0.952	0.955	0.983	0.985	0.984
Uzbekistan	0.877	0.992	1.026	0.996	0.984	0.982	0.984
Venezuela	0.940	0.793	0.982	0.989	1.007	1.008	1.008
Vietnam	0.966	0.825	0.977	0.996	1.008	1.010	1.008
Yemen	0.758	0.835	1.060	0.991	0.977	0.973	0.977
South Africa	0.865	0.778	0.963	0.983	0.997	0.999	0.998
Democratic Republic of the Congo	0.563	0.825	0.986	0.996	0.944	0.945	0.944
Zambia	0.551	0.733	0.999	0.999	0.948	0.948	0.948
Zimbabwe	0.743	0.664	0.998	0.993	0.988	0.988	0.988

Table C5: Variance Decomposition of Impact Estimates

(a) Mobile Labor

	Variance				2 × Covariance		
$\hat{e}$	$\frac{Y}{L}$	X	L	Offset	X, L	X, Offset	L, Offset
0 %	0.149	0.040	0.059	0.001	0.036	-0.001	0.014
1 %	0.148	0.040	0.059	0.001	0.036	-0.001	0.012
2 %	0.146	0.040	0.059	0.001	0.036	-0.000	0.011

(b) Immobile Labor

(c) Variance Decomposition - Immobile Labor

	Variance of logged term				2 × Covariance of logged terms						
$\hat{e}$	$\frac{Y}{L}$	T1	T2	T3	T4	T1, T2	T1, T3	T1, T4	T2, T3	T2, T4	T3, T4
0	0.145	0.059	0.040	0.001	0.001	0.036	-0.001	0.014	-0.005	-0.0003	0.0001
0.100	0.136	0.059	0.040	0.001	0.0002	0.036	-0.001	0.006	-0.005	-0.0001	0.00004
0.200	0.134	0.059	0.040	0.001	0.0001	0.036	-0.001	0.004	-0.005	-0.0001	0.00002

(d) Hybrid Labor

(e) Variance Decomposition - Hybrid Labor

	Variance of logged term				2 × Covariance of logged terms						
$\hat{e}$	$\frac{Y}{L}$	T1	T2	T3	T4	T1, T2	T1, T3	T1, T4	T2, T3	T2, T4	T3, T4
0	0.147	0.059	0.040	0.0002	0.001	0.036	-0.001	0.014	-0.002	-0.001	0.0001
0.100	0.138	0.059	0.040	0.0002	0.0002	0.036	-0.001	0.006	-0.002	-0.0002	0.00002
0.200	0.136	0.059	0.040	0.0002	0.0001	0.036	-0.001	0.004	-0.002	-0.0001	0.00001

C.2 Interactive Country-Level Data Tables

https://bjang.shinyapps.io/appendix_countries/