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Civil War, Climate Change and Development: A Scenario Study for Sub-Saharan Africa

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Abstract: We construct a model of development, civil war, and climate change. There are multiple interactions. Economic growth reduces the probability of civil war and the vulnerability to climate change. Climate change increases the probability of civil war. The impacts of climate change, civil war, and civil war in the neighbouring countries reduce economic growth. The model has two potential poverty traps – a climate-change-induced one and a civil-war-induced one – and the two poverty traps may reinforce one another. We calibrate the model to Sub-Saharan Africa and conduct a double Monte Carlo analysis accounting for both parameter uncertainty and stochasticity. We find the following. Although we use the SRES scenarios as our baseline, and thus assume rapid economic growth in Africa and convergence of African living standards to the rest of the world, the impact of civil war and climate change (ignored in SRES) are sufficiently strong to keep a number of countries in Africa in deep poverty with a high probability. Other countries enjoy exponential growth; and some countries may either be trapped in poverty or experience rapid growth. The SRES scenarios were wrong to ignore the impact of climate change and civil war on economic development.

Key words: civil war; climate change; economic development

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1. Introduction

The socio-economic scenarios that underpin future projections of climate change are very peaceful (Nakicenovic and Swart 2001). This is in sharp contrast to the past, which regularly saw violent conflict between and within states. The absence of (civil) war in future scenarios of climate change is even more surprising when one considers that violent conflict can have a profound impact on development (Butkiewicz and Yanikkaya 2005b); and that one of the more worrying predictions is that climate change would enhance violent conflict (Barnett and Adger 2007). This paper seeks to fill this void by developing a simulation model for the three-way interaction between civil war, climate change and development.

The model has a few, simple components. Climate change may have a negative impact on the economy, slowing down its growth. Climate change may increase the probability of civil war. Civil war has a negative impact on economic growth. In turn, economic growth reduces the vulnerability to the impacts of climate change; and it reduces the probability of an outbreak of violent conflict. Although its components are simple, when put together the model is complex.

As far as we know, this is the first attempt to study this three-way interaction. Essentially, we model a race. Economic growth reduces the risk of conflict and the impact of climate change. But climate change and conflict reinforce one another and reduce economic growth. If the first effect is stronger, countries will be rich, peaceful and not much bothered by climate change. If the latter effect is stronger, countries will be poor, torn by conflict, and suffer from climate change. Phrased like this, the model is used to investigate whether there is a conflict-and-climate-induced poverty trap.

While there are a number of papers on the relationship between conflict and economic growth and on climate change and growth, there is little quantitative evidence on conflict and climate change – see Section 2 for a literature review. Therefore, as a secondary contribution, the paper also develops and estimates a model of the impact of climate change on civil war.

We apply the model to Sub-Saharan Africa, the region that is least developed and most subject to (civil) war.

The paper proceeds as follows. Section 2 reviews the literature. Section 3 presents the model, with additional material in the appendix. Section 4 discusses the results. Section 5 concludes.

2. Previous literature

2.1. Climate and conflict

Existing empirical research on the role of climate change in violent conflict is limited and inconclusive. (Homer-Dixon 1994) examine a number of case studies, in order to determine if environmental scarcities cause violent conflict. Evidence from these case studies suggests that while conflict has indeed occurred in areas of resource scarcity, key contextual factors have played an important role. For example, he argues that serious civil unrest is unlikely to occur unless the political structure prevents challenger groups from expressing their grievances peacefully, but offers these groups an opportunity for violence against authority. Later research (Buhaug and Rod 2006;Dixon 2009;Gleditsch 1998;Gleditsch et al. 2006;Hauge and Ellingsen 1998;Henderson 2000;Henderson and Singer 2000;Hendrix and Glaser 2007;Nordås and Gleditsch 2007;Raleigh 2010;Raleigh and Urdal 2007;Theisen 2008;Urdal 2005) confirmed Homer-Dixon's conclusion. While authors disagree about whether environment and climate are contributing factors to violent conflict, there is a consensus that other factors dominate.

(Collier and Hoeffler 1998) were the first to suggest an "economic theory" of civil conflict – rent-seeking by violence – and to test their predictions with data. Later papers have refined the hypotheses and econometrics (Brunnschweiler and Bulte 2009;Collier et al. 2009;Collier and Hoeffler 2005;Elbadawi and Sambanis 2000;Justino 2009;Schollaert and van de gaer 2009;van der Ploeg and Poelhekke 2010;Welsch 2008;Wick 2008;Wick and Bulte 2006). While these papers tend to find a link between deprivation and conflict and between specific resources and conflict, there is no direct link between climate and conflict. Deprivation has many causes and climate is at best a contributing factor (Acemoglu et al. 2001;Acemoglu et al. 2002;Easterly and Levine 2003;Gallup et al. 1999;Masters and McMillan 2001). People may fight over resources that are highly valuable and easy to smuggle (e.g., diamonds) but they tend not to over bulky goods such as water and food – climate- and weather-sensitive resources are less conflict-prone.

2.2. Conflict and growth

From an economic perspective, the consequences of conflict may be severely damaging. (Collier 1999) investigates the consequences of civil war for GDP, during the conflict years and in the early years following. He finds that during civil wars GDP per capita declines at an annual rate of 2.2 per cent, relative to its counterfactual. This is partly explained by reduced production but is also the result of a gradual loss of the capital stock. Capital-intensive and transaction-intensive sectors will be severely affected: manufacturing, construction, transport, distribution and finance will all contract more rapidly than GDP. Collier argues that the restoration of peace does not necessarily imply a peace dividend, or a large bounce-back effect, as might be expected. He finds that if a civil war lasts only one year, it was found to cause a loss of growth of 2.1 per cent per annum, in the first five years of peace. This loss of growth is not significantly different from the loss that would have been experienced had the war continued. If the war has been sufficiently long however, Collier argues that the repatriation of capital enables the economy to grow rapidly. Empirically he finds that after a 15-year war, the post-war growth rate is enhanced by 5.9 per cent per annum. Later papers find similar effects, and also study the spillover effects on neighboring countries and trading partners (Asteriou and Price 2001;Azam et al. 2002;Bayer and Rupert 2004;Bozzoli et al. 2010;Butkiewicz and Yanikkaya 2005a;Carmignani 2003;De Groot 2010;Fosu 2003;Gyimah-Brempong and Corley 2005;Kang and Meernik 2005;Koubi 2005;Murdoch and Sandler 2002).

2.3. Climate and growth

(Dell et al. 2008;Fankhauser and Tol 2005) study the impact of climate change on economic growth. They conclude that climate change is likely to slow economic growth, and perhaps significantly so, but is unlikely to reverse growth.

3. The model

3.1. Overview

The structure of the model is as follows. See Figure 1. There are six equations. The risk of civil war is higher if people are poorer, if economic growth is slower, and if more people are affected by drought (Equation (1)). The risk of drought is higher if people are poorer and there is less precipitation (Equation (2)). Precipitation changes with climate (Equation (3)). The number of people affected by drought, assuming there is one, falls as people grow richer (Equation (4)). The impact of climate change gets worse as climate change gets more severe and as people are poorer (Equation (5)). Economic growth is slower if a there is civil war in the own country or in a neighbouring country, and if the impact of climate change is more negative (Equation (6)). These equations make intuitive sense – the specifications and parameters are discussed below.

The qualitative behaviour of the model is as follows. Climate change affects the impact of climate change and the risk of civil war. Economic growth affects the impact of climate change and is affected by it. Economic growth affects the risk of civil war and is affected by it. This means that there are two potential poverty traps in the model – sluggish growth leading to civil war further slow growth; climate change slowing growth enhancing vulnerability to climate change – and the two poverty traps may reinforce one another.

3.2. Equations

The risk of civil war is based on (Collier et al. 2009); see Appendix 1 for more detail. It is given by

(1) $$W_{c,t} = \frac{1}{1+e^{-Z_{c,t}}} \text{ with } Z_{c,t} := \alpha_0 + \alpha_{1,c} + \alpha_2 \ln y_{c,t} + \alpha_3 \frac{y_{c,t} - y_{c,t-1}}{y_{c,t-1}} + \alpha_4 A_{c,t}$$

where

- $W_{c,t}$ is the risk of civil war in country *c* at time *t*;
- *c* indexes countries;
- *t* indexes time;
- $y_{c,t}$ is per capita income in country *c* at time *t*;
- $A_{c,t}$ is the number of people (per million inhabitants) affected by drought in country *c* at time *t*; these parameters are estimated; see Appendix 1;

- α_2=-0.33 (0.12), α_3=-0.061 (0.030) and α_4=0.0073 (0.0040) are parameters;
- $\alpha_{1,c}$ is a country specific constant[1]; see Appendix 2; and
- α_0 is a calibration constant such that the probability of a civil war is 6% in 2005 (when 3 out of 50 sub-Saharan African countries were at civil war); calibration is necessary in the Monte Carlo analysis over the other parameters in Equation (1).

The risk of drought is given by

$$D_{c,t} = \frac{1}{1+e^{-Z_{c,t}}} \text{ with } Z_{c,t} := \beta_0 + \beta_1 \ln y_{c,t} + \beta_2 P_{c,t} \tag{2}$$

where

- $D_{c,t}$ is the risk of drought in country *c* at time *t*;
- $P_{c,t}$ is precipitation in country *c* at time *t*; see Appendix 2; and
- β_0=4.0 (0.4), β_1=-0.75 (0.06) and β_2=0.00025 (0.00010) are parameters; these parameters are estimated; see Appendix 1.

Precipitation follows

$$P_{c,t} = \eta_{c,0} + \eta_{c,1} T_t \tag{3}$$

where

- T_t is the global mean surface air temperature (in degree Celsius above pre-industrial); and
- $\eta_{c,0}$ and $\eta_{c,1}$ are country-specific parameters taken from (Hesselberg Christensen et al. 2007); see Appendix 2.

The number of people affected by drought is given by

$$A_{c,t} = \begin{cases} \gamma_0 + \gamma_1 \ln y_{c,t} & D*_{c,t} = 1 \\ 0 & D*_{c,t} = 0 \end{cases} \tag{4}$$

where

- $D*_{c,t}$ is drought in country *c* at time *t*; and
- γ_0=34 (16), and γ_1=-4.1 (2.4) are parameters; these parameters are estimated; see Appendix 1.

The impact of climate change is given by

$$C_{c,t} = \lambda_{c,0} + \lambda_1 \ln y_{c,t} + \lambda_2 T_t^2 \tag{5}$$

where

- $C_{c,t}$ is the impact of climate (in percent of GDP) in country *c* at time *t*;

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[1] Note that the econometric model as estimated by (Collier et al. 2009) and re-estimated by ourselves contain a number of other control variables, which are held constant during the simulations.

- T_t is the global mean surface air temperature (in degree Celsius above pre-industrial); and
- λ_1=0.00010 (0.00001); and λ_2=-0.48 (0.01) are parameters; $\lambda_{c,0}$ is a country-specific constant; these parameters estimated as a statistical surface of the *FUND* 2.8n model; see Appendix 3.

Economic growth is given by

(6a) $$y_{c,t} = (1 + g_{c,t}) y_{c,t-1}$$

(6b) $$g_{c,t} = \kappa_{c,t,0} + \kappa_1 W^*_{c,t-1} + \kappa_2 \sum_{j \neq c} W^*_{j,t-1} I_{c,j} + \kappa_3 C_{c,t-1}$$

where

- g is the growth rate of country c at time t;
- $W^*_{c,t}$ denotes civil war in country c at time t;
- I is an indicator function, one if countries c and j share a border, and zero otherwise;
- κ_1=0.022 (0.011); κ_2=0.009 (0.004) and κ_3=0.05 (0.02) are parameters; these parameters are calibrated; $\kappa_{c,t,1}$ is a country- and period-specific constant; see Appendix 2.

3.3. Simulations

We conduct a double Monte Carlo analysis. In the outer loop, we consider parameter uncertainty. We use a Latin Hypercube sample of all parameters (cf. Section 3.2) of size 60. In the inner loop, we consider stochasticity, particularly the outbreak of civil war and drought. We use a simple sampling scheme with 2,000 runs. This makes a total of 120,000 runs.

4. Results

The model has six variables: temperature (as an indicator of climate change), the probability of drought, the number of people affected by drought, the economic impact of climate change, the probability of civil war, and per capita income. We are primarily interested in the latter three variables, and particularly the evolution of per capita income and the possible of a climate-change-induced poverty trap. Nevertheless, the first three variables are needed to understand the behaviour of the model and the results. We therefore briefly discuss these before turning to the main findings.

There are many countries in the model, many runs in the Monte Carlo analysis of parameter uncertainty, and many runs in the Monte Carlo analysis of war and drought stochasticity. That is, there are a lot of results. We present and interpret the results mainly for the expected values for three countries, the Democratic Republic of the Congo (Kinshasa), Lesotho, and Gabon, which are the countries with the lowest, median, and highest expected per capita income in 2100.

Figure 2 shows the global mean temperature over the 21st century. It is assumed to rise from 0.8 ºC to 3.1-3.7ºC over the course of the century. The atmospheric concentration of carbon dioxide is highest in the A2 scenario but so are sulphur emissions; the A1 scenario therefore shows the highest temperature. The B1 scenario shows the least warming. Precipitation is assumed to be a linear function of temperature – see Equation (3) – and thus shows the same pattern as temperature.

Figure 3 shows the number of people affected by drought over the 21st century for the A1 scenario. As "drought" is defined as drought that does reportable damage – see Equation (2) – it depends also on per capita income – see Figure 1 – and is therefore an uncertain and stochastic variable. The number of people affected further depends on per capita income – see Equation (2). Figure 3 therefore displays the expected value of the number of people affected by drought. For Lesotho, about five people in a million suffer from drought in 2005. This falls by a factor eight over the course of the century. For Gabon, the drop is much steeper: a factor 33; and from a lower base at that: one person in a million. The reverse is observed for the Congo. Some twelve people in a million are affected by drought in 2005; this falls at first, but then starts rising again in the second half of the century to about ten people in a million in 2100. There is a strong divergence between the countries of Sub-Saharan Africa with regard to the seriousness of drought.

Figure 3 also shows results for the median country (Lesotho) under the four alternative scenarios. Results are very similar for A1 and B1, but the incidence of drought is considerably higher under B2 and particularly A2. These differences are primarily due to the assumed growth of per capita income; the change in precipitation has little impact.

Figure 4 shows the expected impact of climate change over the 21st century. For Lesotho, climate change reduces welfare equivalent to losing over 4% of income in 2010 rising to over 8% in 2100. For the Congo, the impact in 2100 would be almost 13% of GDP. The pattern for Gabon is different. A loss of 3% at the start of the century is turned into a gain of the same size by the end of the century as development has removed the main vulnerabilities to climate change and opened new opportunities to take advantage of climate change. As with drought, there is a strong divergence between countries.

Figure 4 also shows results for Lesotho under the four alternative scenarios. Impacts are less severe under B1 than under A1, primarily because climate change is less pronounced under B1 (cf. Figure 2). Impacts are more severe under B2 and worse still under A2. These differences are largely because of differences in per capita income.

Figure 5 shows the expected probability of civil war over the 21st century. For Lesotho, the probability of civil war starts at 2%, increases to over 5% and then tapers off to 3% as climate change is the dominant signal in the medium term but development is the dominant signal in the long term. For Gabon, the expected probability of civil war starts at a low 0.4% and falls to almost zero. For the Congo, the expected probability of civil war starts high (69%) and remains high (62%). As with drought and climate change impacts, there is a strong divergence between countries.

Figure 5 also shows results for Lesotho under the four alternative scenarios. Results are almost identical for the A1 and B1 scenarios. However, the risk of civil war is higher under the B2 scenario and higher still under the A2 scenario. These differences and similarities primarily reflect differences in the assumed economic growth rate; climate change has a minor impact.

Figure 6 shows the expected income per capita over the 21st century. For Lesotho, income rises from some $500 per person per year at the start of the century to almost $13,000/p/y at the end – a 26-fold increase. For the Cong, income rises too but only 7-fold from less than $100/p/y to less than $700/p/y. For Gabon, income rises 90-fold from $4,000/p/y to $350,000/p/y. As with the previous three indicators, there is divergence, big time.

Figure 6 also shows results for Lesotho for the four alternative scenarios. Per capita income is roughly the same under A1 and B1. However, it is much lower under B2 and lower still under A2. This partly reflects the assumptions, but the differences are enhanced by the impacts of civil war and climate change on economic growth.

Figure 7 shows the expected income per capita in 2100 for Lesotho for the complete model, for the model with the risk of civil war set to zero, for the model with the impact of climate change set to zero, and for the model with climate change set to zero. Civil war and the economic impact of climate change have a similar effect (but note that the two interact): without civil war, Lesotho would expect to be $3200/p/y richer in 2100; without the economic impacts of climate change, per capita income would be $3300 higher. Without climate change and civil war, income would be $7600 higher. There is therefore a negative synergy between the economic impacts of climate change and civil war. Without climate change (but with the baseline risk of civil war), income would be $1500 higher. Climate change thus more than doubles (from $1500 to $3300) the negative economic impacts of civil war.

Figure 8 shows the expected impact of climate change in 2100 for Lesotho for the complete model, and for the model with the risk of civil war set to zero. The effect of civil war is small, raising the impact from 7.4% to 7.7% of GDP.

Figure 9 shows the expected probability of civil war over the 21st century for the complete model, for the model without the impact of climate change on civil war, and for the model with the impact of climate change set to zero. The direct impact of climate change is modest and mixed; climate change accentuates the pattern seen in Figure 5. The economic impacts of climate change, through their effect on economic growth, increase the probability of civil war by 1% in 2100. While absolute small, this is relatively large as the probability is 4% without the economic impacts of climate and 5% with.

Figure 10 shows the probability density function of per capita income in the year 2100. The distribution for Lesotho shows clear bimodality, as indeed suggested by the qualitative discussion of the model properties. The primary mode is an income of around $14,000 per person per year; the secondary mode is around $9,000/p/y. Less than 10 (out of 120,000) realizations are greater than $18,000/p/y, while the model without climate change and civil war would lift the average income in 2100 to $20,000/p/y. The impact of climate change and civil war on economic growth is unambiguously negative.

The probability distribution for Gabon is unimodal, with a single peak around $356,000/p/y. This is lower than the scenario without climate change and civil war ($425,000/p/y). Interestingly, although the economic impact of climate change is expected to be positive for Gabon (cf. Figure 4), only 33 (out of 120,000) realizations see a net acceleration of economic growth over the century. This is because the negative impacts on growth in the early years are more important than the positive effects in later years.

Congo's probability distribution is unimodal too, with a single peak at subsistence level. Without climate change and civil war, Congo's income would be about $10,000/p/y in 2100. With climate change and civil war, income never exceeds $4,000/p/y.

Combining the three probability density functions, we see that climate change and civil war have a limited effect on the economic development of some countries, a devastating effect on others, and may or may not have a substantial effect on yet other countries. This is confirmed by Figure 11, which shows the probability density function of the growth of per capita income between 2005 and 2100 for all countries in the model. While the baseline scenario without climate change and civil war (cf. Appendix 2) assumes rapid growth for all countries, the combination of civil war and climate change puts different countries in a dramatically different position, with some economies being trapped in subsistence and other countries experiencing (by the end of the century) levels of comfort that exceed current living standards in the OECD.

Figure 11 also shows evidence for multi-modality, particularly for countries in the middle of the range. According to the model, some countries are firmly trapped in poverty; other countries are certain to escape; while yet other countries may or may not escape subsistence.

5. Discussion and conclusion

In this paper, we construct a model of development, civil war, and climate change. There are multiple interactions. Economic growth reduces the probability of civil war and the vulnerability to climate change. Climate change increases the probability of civil war. The impacts of climate change, civil war, and civil war in the neighbouring countries reduce economic growth. The model has two potential poverty traps – a climate-change-induced one and a civil-war-induced one – and the two poverty traps may reinforce one another. We calibrate the model to Sub-Saharan Africa and conduct a double Monte Carlo analysis accounting for both parameter uncertainty and stochasticity.

We find the following. Although we use the IPCC SRES scenarios as our baseline, and thus assume rapid economic growth in Africa and convergence of African living standards to the rest of the world, the impact of civil war and climate change (ignored in SRES) are sufficiently strong to keep a number of countries in Africa in deep poverty with a high probability. There are also economies that would in all likelihood enjoy the very high rates of growth that are assumed in the SRES scenarios. And there are countries in between which may be trapped in poverty or may experience exponential growth – depending on the roll of the dice.

The following caveats apply. The model has simple, aggregate representations of complex and diverse phenomena. For example, we do not distinguish between civil wars of different intensities, and treat climate change impacts as a deadweight loss to the economy. The model lacks a number of mechanisms that may affect our findings. These include human and physical capital, fertility, development assistance, and interstate war. That said, the model is calibrated with realistic numbers, and shows that conflict and climate change matter for development. This justifies repeating the analysis here with more complex models. However, while simple and open for improvement, the analysis here shows that the SRES scenarios were wrong to ignore the impact of civil war and climate change on future economic development.

Acknowledgements

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Table 1. Parameters

Symbol	Description	Value	Source
α_0	Basic risk of civil war	Calibrated	
α_1	Effect of log income on civil war	-0.33 (0.12)	App 1
α_2	Effect of income growth on civil war	-0.061 (0.030)	App 1
α_3	Effect of drought on civil war	0.0073 (0.0040)	App 1
β_0	Basic risk of drought	4.0 (0.4)	App 1
β_1	Effect of log income on drought	-0.75 (0.06)	App 1
β_2	Effect of precipitation on drought	0.00025 (0.00010)	App 1
$\eta_{c,0}$	Precipitation in 2005	Table A2.1	App 2
$\eta_{c,1}$	Effect of climate change on precipitation	Table A2.1	App 2
γ_0	Constant number of people affected by drought	34.2 (15.6)	App 1
γ_1	Effect of log income on number of people affected by drought	-4.05 (2.42)	App 1
λ_c	Basic impact of climate change	Table A2.1	App 2
λ_1	Effect of income on impact of climate change	$1.0\ 10^{-4}$ ($0.1\ 10^{-4}$)	App 3
λ_2	Effect of temperature squared on impact of climate change	-0.48 (0.01)	App 3
$\kappa_{c,t}$	Basic income growth rate	Table A2.1	App 2
κ_1	Effect of own civil wars on economic growth	0.022 (0.011)	Collier
κ_2	Effect of neighbours' civil wars on economic growth	0.009 (0.004)	Collier
κ_3	Effect of climate change impact on economic growth	0.05 (0.02)	Collier

Table 2. Variables

Symbol	Description	Unit	Equation
$W^{(*)}$	(Risk of) civil war	Number of conflicts per year	1
$D^{(*)}$	(Risk of) drought	Dummy variable	2
P	Precipitation	Millimetres per year	3
A	Number affected by drought	People per million inhabitants	4
C	Impact of climate change	Percent of gross domestic product	5
y	Per capita income	Dollar per person per year	6

Figure 1. Flow diagram of the model

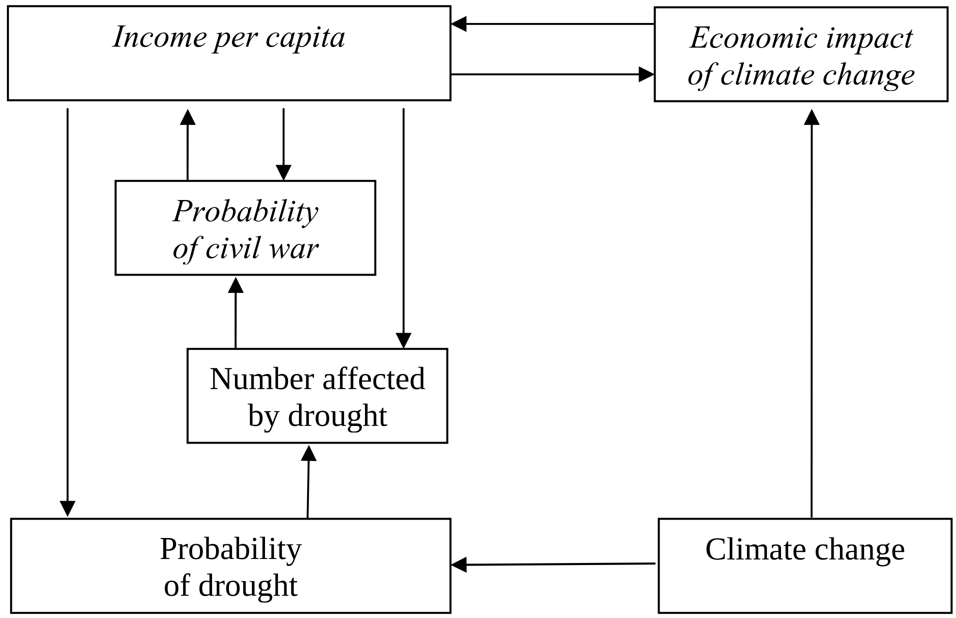


Figure 2. The global mean temperature for the four scenarios.

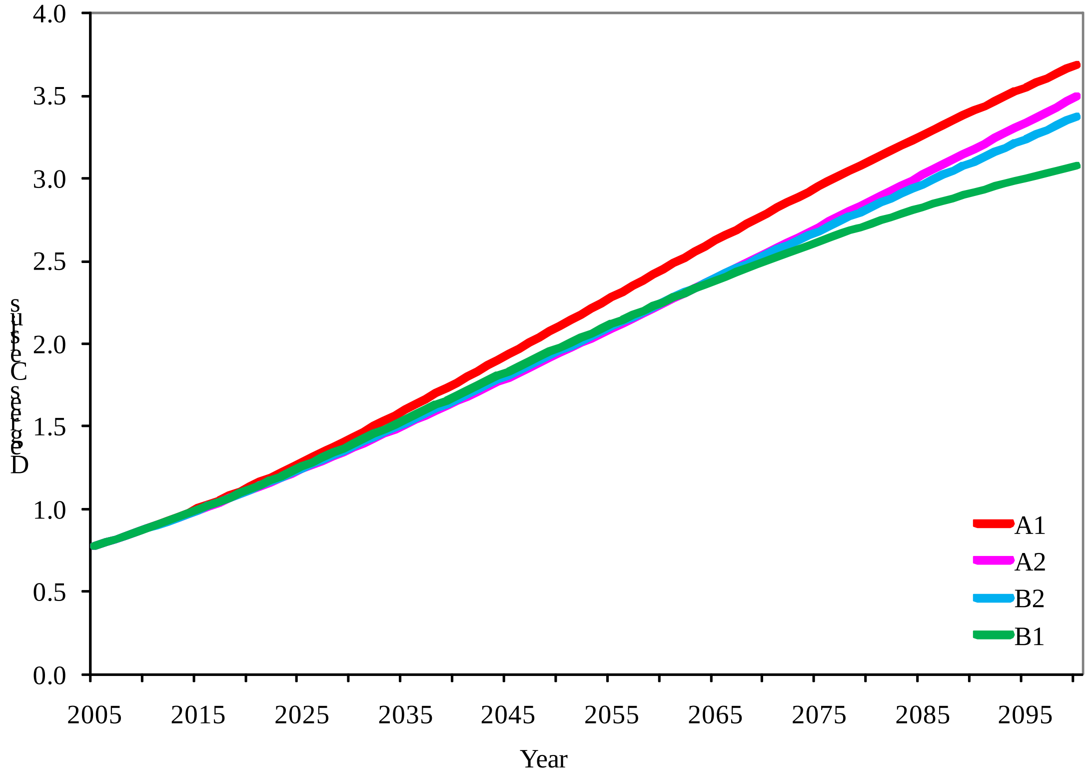


Figure 3. The expected fraction of people affected by drought for the best off (Gabon), worst off (DR Congo), and median (Lesotho) country in 2100.

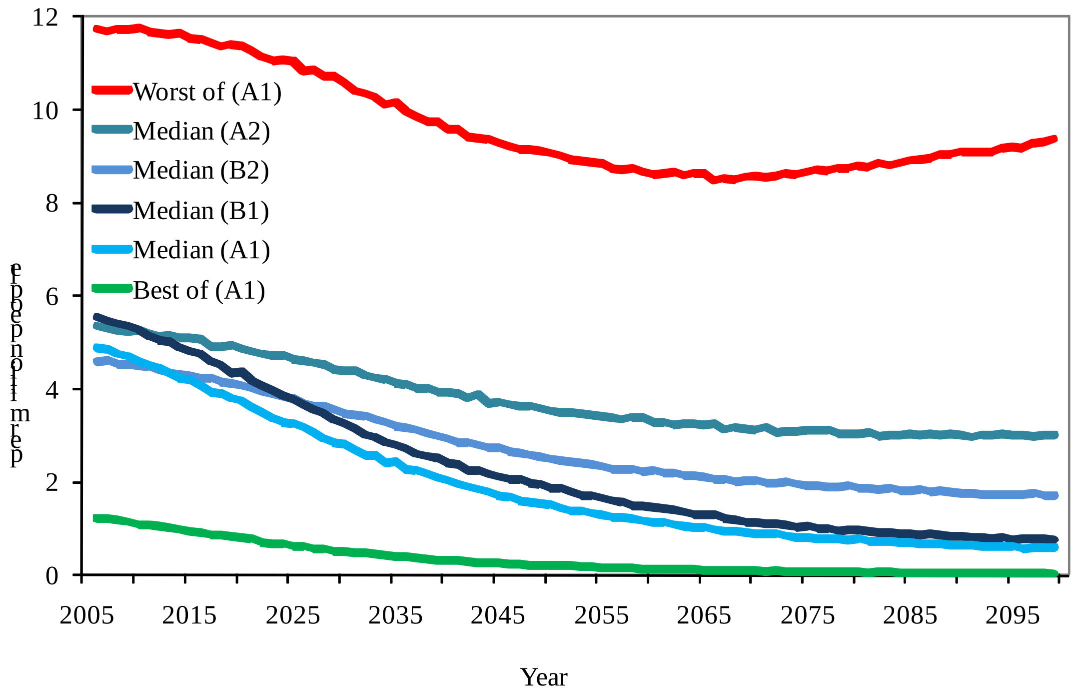


Figure 4. The expected impact of climate change for the best off (Gabon), worst off (DR Congo), and median (Lesotho) country in 2100.

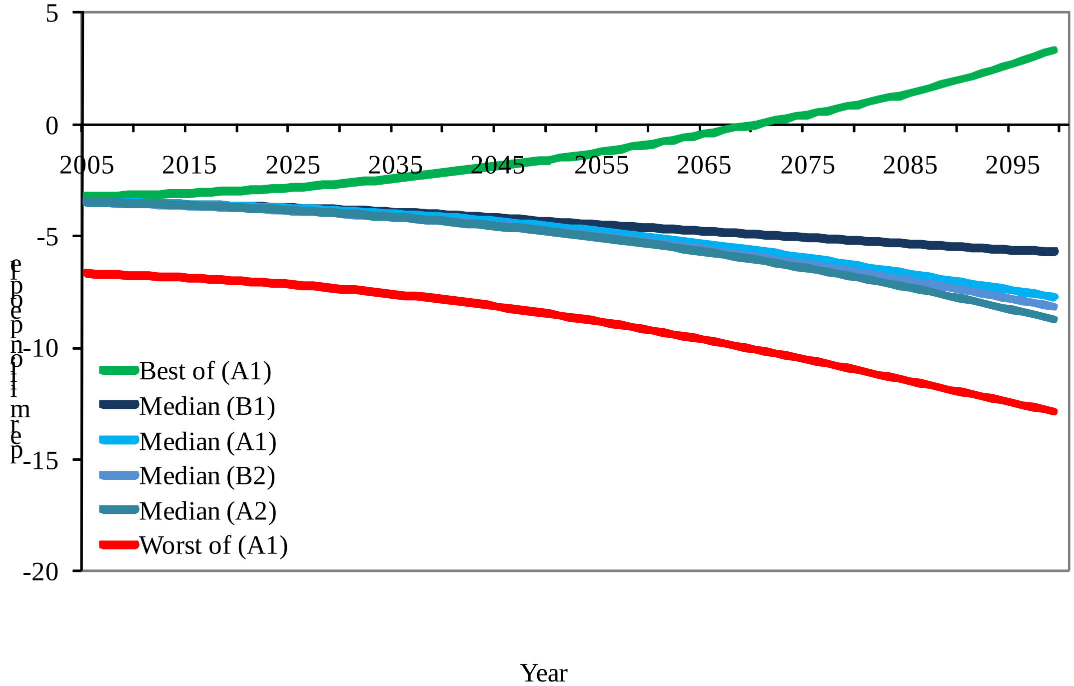


Figure 5. The expected probability of civil war for the best off (Gabon), worst off (DR Congo), and median country (Lesotho) in 2100.

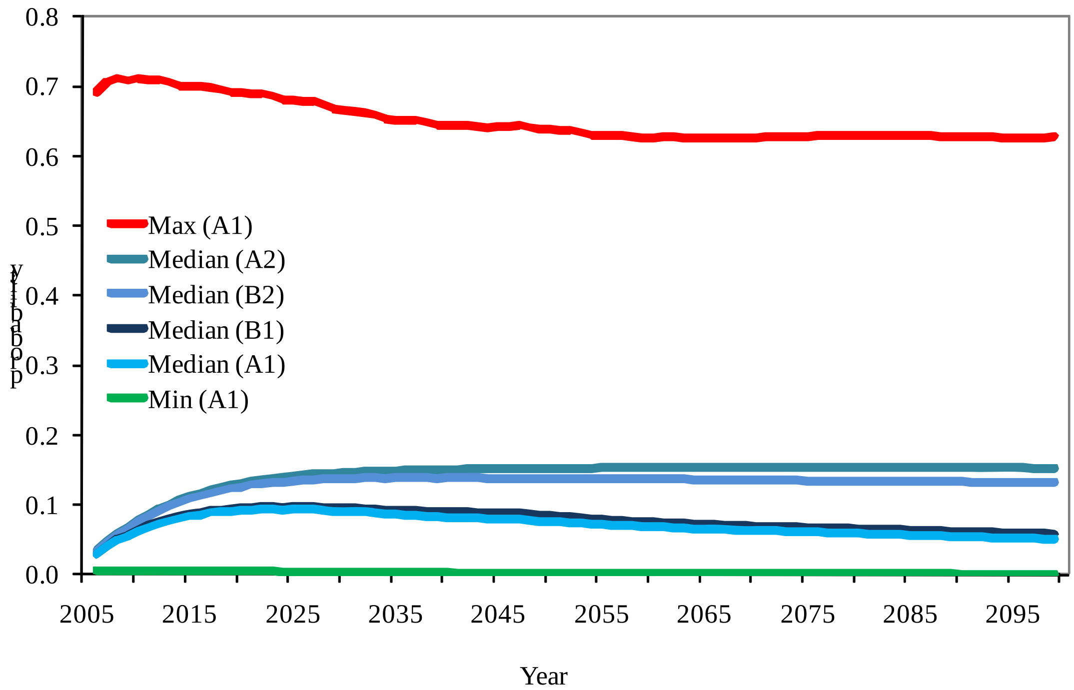


Figure 6. The expected per capita income for the best of (Gabon), worst of (DR Congo), and median country (Lesotho) in 2100.

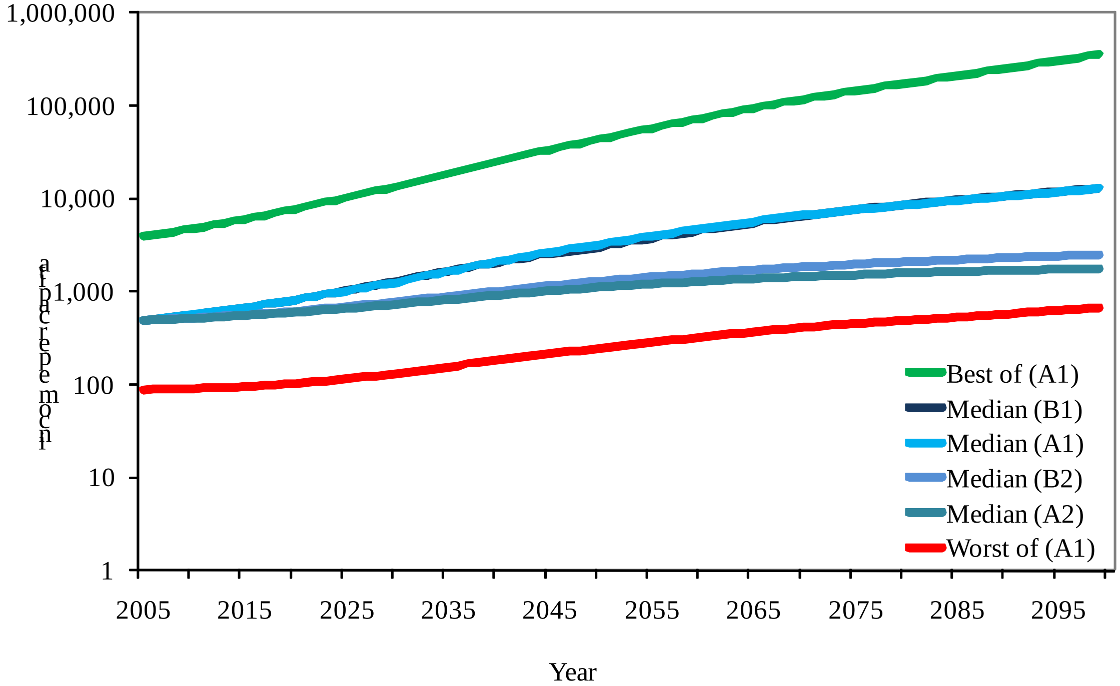


Figure 7. The expected per capita income for the median country (Lesotho) in 2100 for the full model, the model without the risk of civil war, the model without the economic impacts of climate change, and the model without climate change.

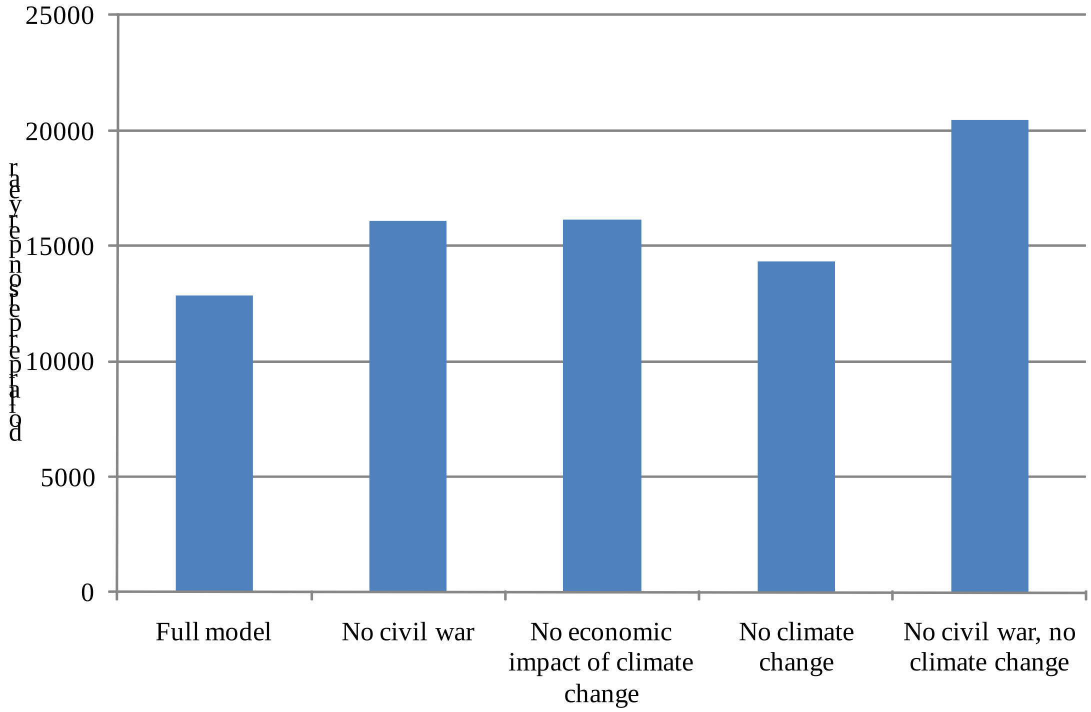


Figure 8. The expected impact of climate change for the median country (Lesotho) in 2100 with and without the risk of civil war.

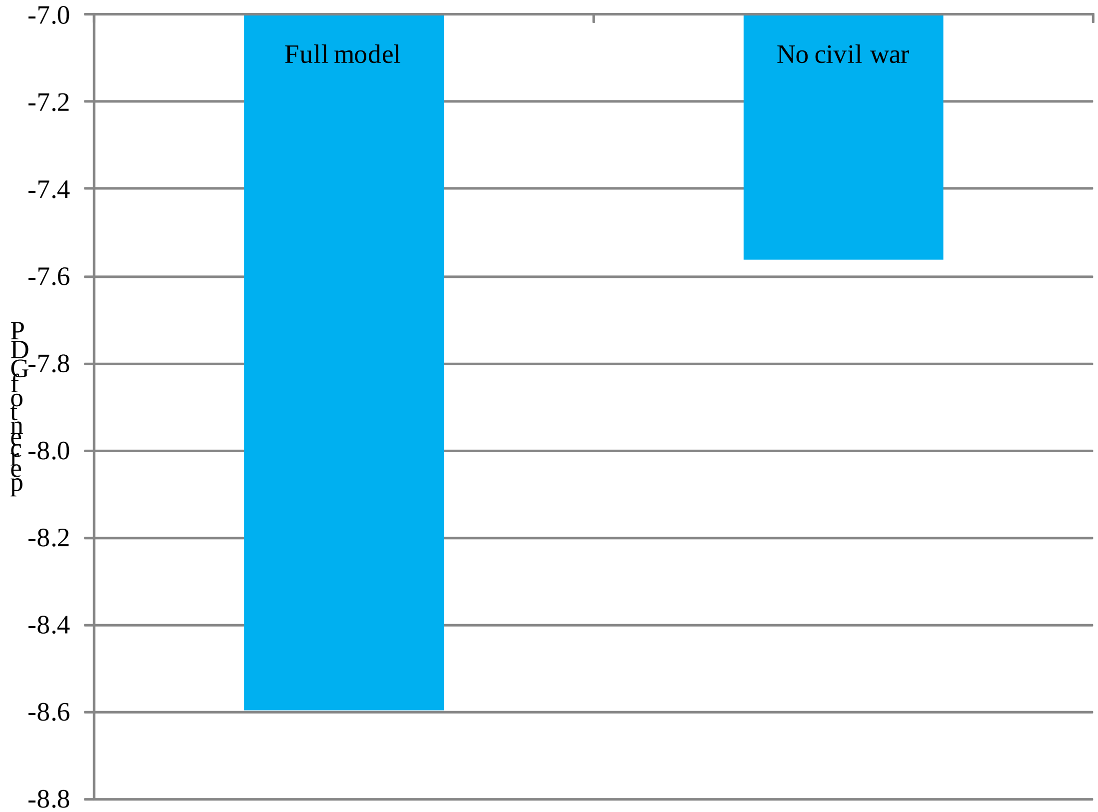


Figure 9. The expected probability of civil war for the median country (Lesotho) in 2100 with and without economic impacts of climate change and the impact of climate change on civil war.

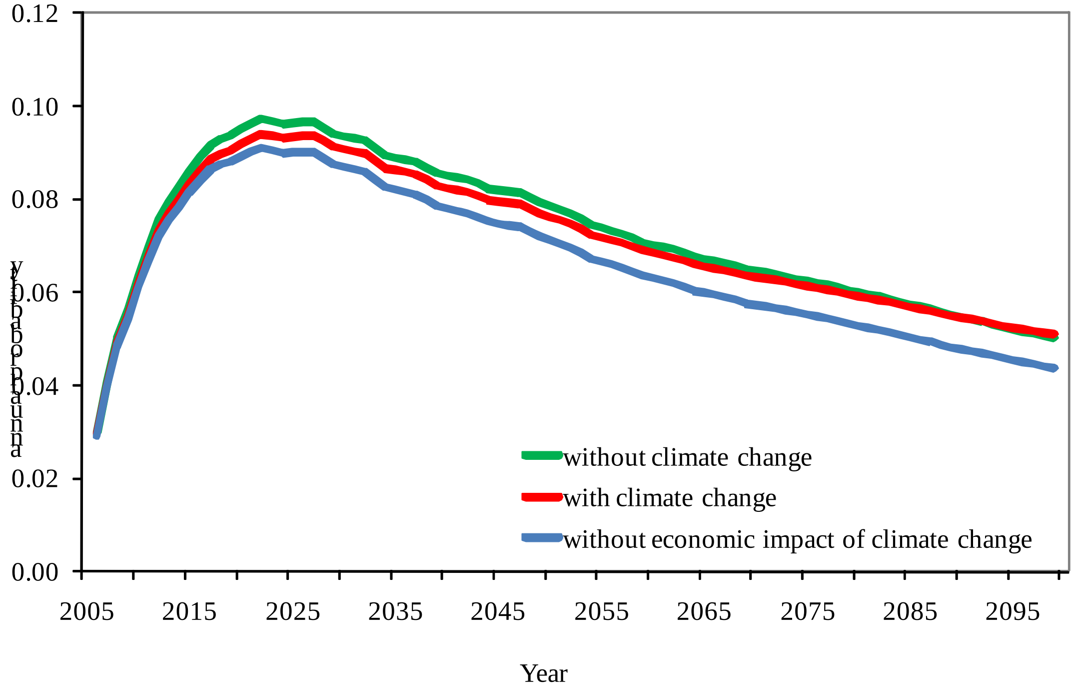
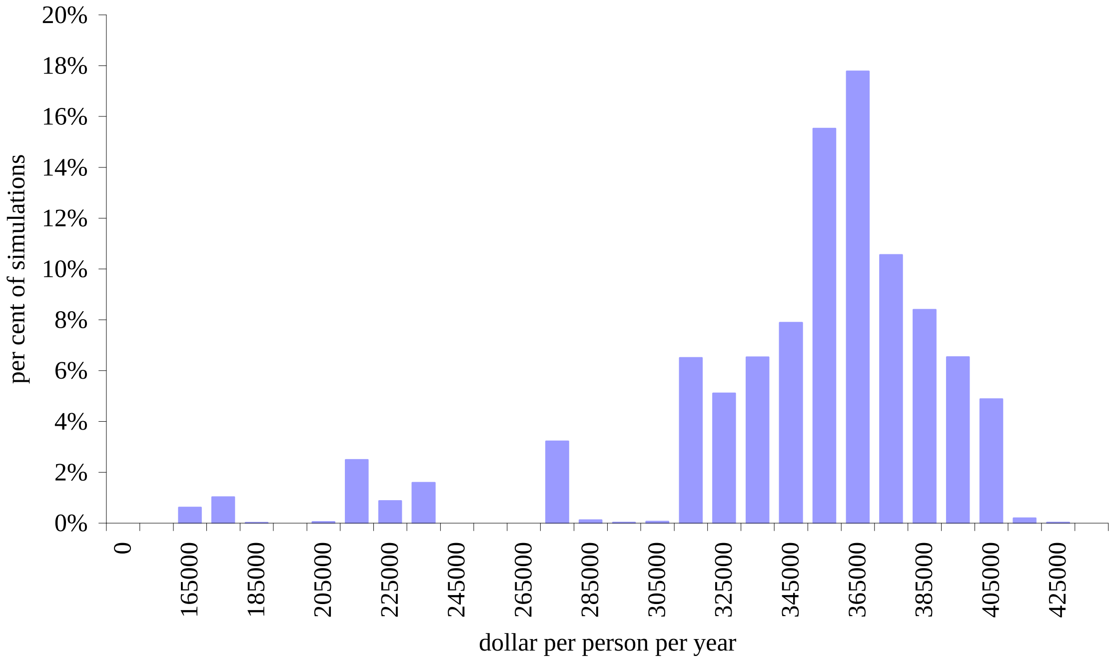
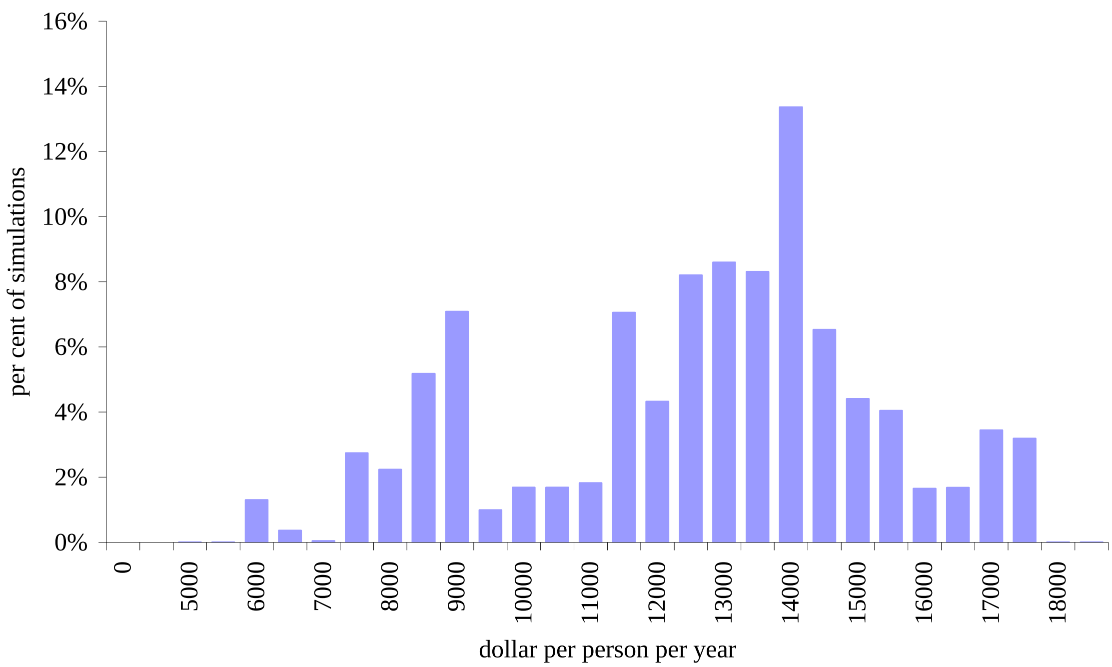


Figure 10. The probability density function of the per capita income in 2100 in the best of (Gabon), worst of (DR Congo) and median country (Lesotho).

Gabon



Lesotho



Democratic Republic of the Congo

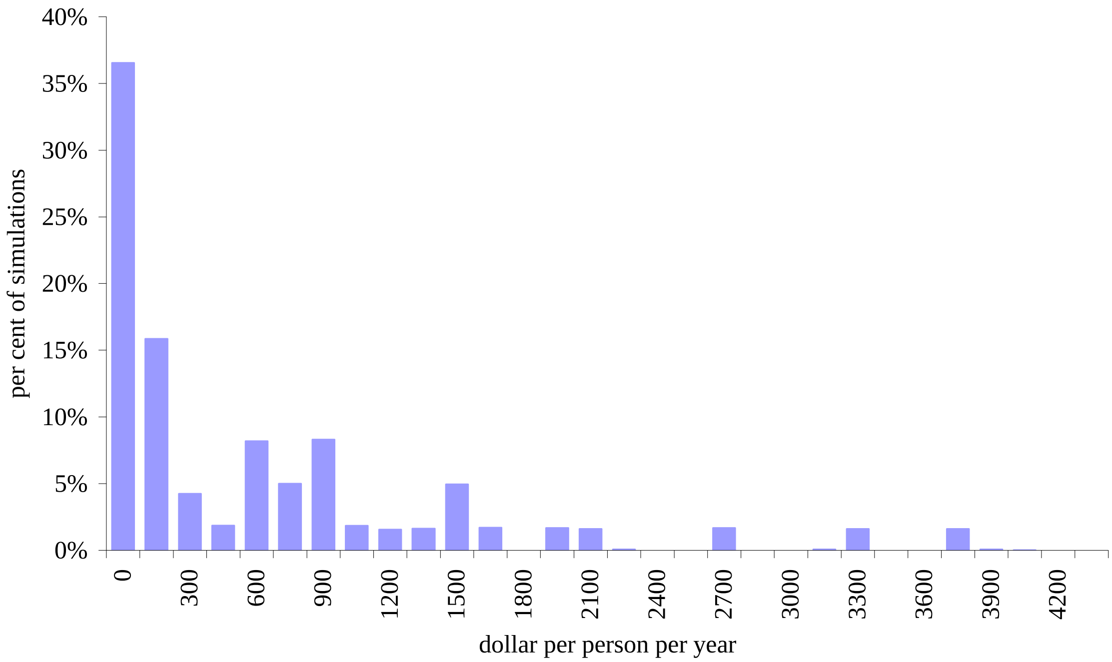
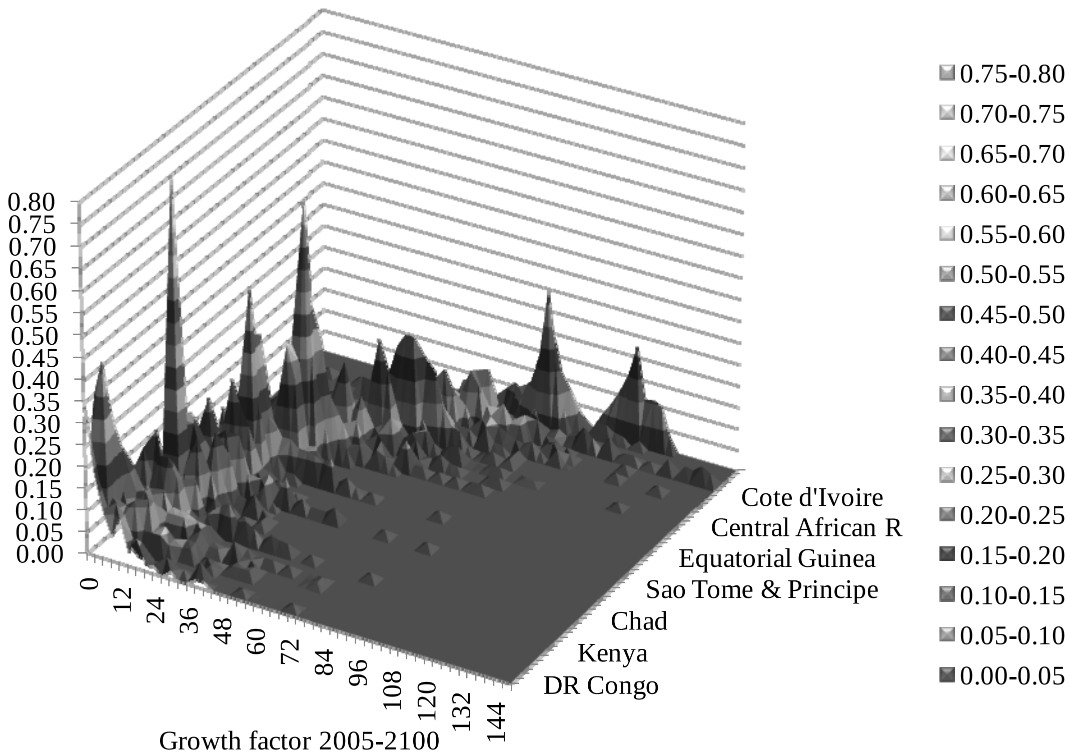


Figure 11. The probability density function of the growth factor of per capita income between 2005 and 2100 for all countries in the model; countries are ordered with respect to their model growth.



Appendix 1: Regression results

(Collier et al. 2009) estimate a logit model of the probability of an outbreak of civil war. We re-estimated their model, adding variables that would be sensitive to climate change. Specifically, we added cereal production (total, wheat, maize, coarse grains), precipitation, and the number of people affected by drought. We also added the number of immigrants and the stock of immigrants, which would be affected by sea level rise, among other things. Only the number of people affected by drought has a significant effect on the probability of civil war. We use a general-to-specific strategy with joint significance tests (Hendry 1995) to find the model specification given in Table A1.

Table A2 shows the results of a logit regression of the occurrence of drought (according http://www.emdat.be/) on income and growth. Table A3 shows the results of a regression of the number of people affected by drought on per capita income.

Table A1. Regression results for the occurrence of civil war

Symbol	Description	Mean	StDev	z-stat
α_1	Ln(per capita income)	-0.3266	0.1210	-2.70
α_2	Income growth	-0.06095	0.02975	-2.05
α_0	Time since previous conflict	-0.05934	0.00954	-6.22
α_0	Former colony of France	-1.256	0.559	-2.25
α_0	Social fractionalization	1.752	0.723	2.42
α_3	Number affected by drought	0.007352	0.004015	1.83
α_0	Intercept	0.9811	0.8683	1.13
	Pseudo R^2	0.221	N	956

Table A2. Regression results for the occurrence of drought

Symbol	Description	Mean	StDev	z-stat
β_1	Ln(per capita income)	-0.746	0.064	-11.7
β_2	Income growth	-0.000248	0.000099	2.51
β_0	Intercept	3.948	0.444	8.89
	Pseudo R^2	0.147	N	1347

Table A3. Regression results for the number of people affected by drought (per million inhabitants), conditional on drought occurring

Symbol	Description	Mean	StDev	z-stat
β_1	Ln(per capita income)	-4.05	2.42	-1.68
β_0	Intercept	34.2	15.6	2.20
	R^2	0.012	N	240

Appendix 2: Country-specific parameters

	Precip[a]	Climate change impact		Income[d]	Growth factor per capita income 2005-2100[e]			
	mm/yr	mm/K[b]	% GDP[c]	$/p/yr	A1	A2	B1	B2
Angola	1010	-3.6	-5.18	928	67	10	67	14
Benin	1039	7.4	-4.71	321	108	15	108	20
Botswana	416	-5.9	-3.82	4382	41	7	41	9
Burkina Faso	748	5.3	-5.19	253	108	15	108	20
Burundi	1218	30.5	-6.31	100	140	18	140	25
Cameroon	1604	11.5	-3.34	678	108	15	108	20
Cape Verde	424	3.0	-1.79	1343	108	15	108	20
Cote d'Ivoire	1348	9.6	-3.25	560	108	15	108	20
Central African Rep	1343	21.6	-4.56	218	123	16	123	23
Chad	322	-2.3	-3.94	274	71	13	54	19
Comoros	1754	43.9	0.12	386	140	18	140	25
Congo	1646	11.8	-4.93	1101	108	15	108	20
Congo, Dem Rep	1543	24.8	-6.60	89	123	16	123	23
Djibouti	220	5.5	-4.86	793	140	18	140	25
Equatorial Guinea	2156	15.4	-6.46	8098	108	15	108	20
Eritrea	384	9.6	-5.74	167	140	18	140	25
Ethiopia	848	21.2	1.46	138	140	18	140	25
Gabon	1831	13.1	-4.46	4279	108	15	108	20
Gambia	837	6.0	-6.92	314	108	15	108	20
Ghana	1187	8.5	-4.36	282	108	15	108	20
Guinea	1651	11.8	-4.41	402	108	15	108	20
Guinea-Bissau	1577	11.3	-13.45	134	108	15	108	20
Kenya	692	17.3	-4.87	426	140	18	140	25
Lesotho	789	-11.3	-3.71	496	41	7	41	9
Liberia	2391	17.1	-4.22	129	108	15	108	20
Madagascar	1513	-21.6	-5.32	233	41	7	41	9
Malawi	1181	-16.9	-6.83	138	41	7	41	9
Mali	282	0.5	-4.44	284	81	15	62	21
Mauritania	92	0.2	-3.41	444	81	15	62	21
Mauritius	2041	-29.2	-3.43	4403	41	7	41	9
Mozambique	1032	-14.7	-13.32	312	41	7	41	9
Namibia	285	-4.1	-3.19	2133	41	7	41	9
Niger	151	-1.1	-3.76	166	71	13	54	19
Nigeria	1150	8.2	-4.43	428	108	15	108	20
Reunion	2051	-29.3	-4.71	1076	41	7	41	9
Rwanda	1212	30.3	-5.99	255	140	18	140	25
Saint Helena	750	-10.7	-4.71	501	41	7	41	9
Sao Tome & Principe	2169	15.5	-4.71	1076	108	15	108	20
Senegal	687	4.9	-4.71	1076	108	15	108	20
Seychelles	1970	49.3	-2.43	6789	140	18	140	25
Sierra Leone	2526	18.0	-4.69	215	108	15	108	20
Somalia	282	7.1	-4.71	1076	140	18	140	25
South Africa	495	-7.1	-3.68	3429	41	7	41	9
Sudan	417	0.7	-3.10	459	81	15	62	21
Swaziland	788	-11.3	-3.70	1381	41	7	41	9
Tanzania	1071	26.8	-6.33	324	140	18	140	25
Togo	1168	8.3	-4.71	237	108	15	108	20

Uganda	1180	29.5	-5.87	269	140	18	140	25
Zambia	1020	5.5	-4.94	356	76	11	76	15
Zimbabwe	692	-9.9	-2.83	428	41	7	41	9

[a] Average annual precipitation, 1961-1990
[b] the impact of the enhanced greenhouse effect on precipitation
[c] the economic impact of climate change
[d] average per capita income in 2005
[e] the projected growth in per capita income (without climate change and without civil war)

Appendix 3: The FUND model

We use version 2.9 of the Climate Framework for Uncertainty, Negotiation and Distribution (FUND). Version 2.9 of FUND has the same basic structure as that of Version 1.6 (Tol 1999;Tol 2001;Tol 2002c), except for the impact module (Tol 2002a;Tol 2002b). The source code and a complete description of the model can be found at http://www.fund-model.org/.

Essentially, FUND is a model that calculates damages of climate change and impacts of greenhouse gas emission reduction for 16 regions of the world by making use of exogenous scenarios of socioeconomic variables. The scenarios comprise of projected temporal profiles of population growth, economic growth, autonomous energy efficiency improvements and carbon efficiency improvements (decarbonization), emissions of carbon dioxide from land use change, and emissions of methane and of nitrous oxide. Carbon dioxide emissions from fossil fuel combustion are computed endogenously on the basis of the Kaya identity. The calculated impacts of climate change perturb the default paths of population and economic outputs corresponding to the exogenous scenarios. The model runs from 1950 to 2300 in time steps of a year, though the outputs for the 1950-2000 period is only used for calibration, and the years beyond 2100 are used for the approximating the social cost of carbon under low discount rates. The scenarios up to the year 2100 are based on the EMF14 Standardized Scenario, which lies somewhere in between IS92a and IS92f (Leggett et al. 1992). For the years from 2100 onward, the values are extrapolated from the pre-2100 scenarios. The radiative forcing of carbon dioxide and other greenhouse gases used by FUND is determined based on Shine *et al*. (1990). The global mean temperature is governed by a geometric buildup to its equilibrium (determined by the radiative forcing) with a half-life of 50 years. In the base case, the global mean temperature increases by 2.5˚C in equilibrium for a doubling of carbon dioxide equivalents. Regional temperature increases, which are the primary determinant of regional climate change damages (except for tropical cyclones, as discussed below), are calculated from the global mean temperature change multiplied by a regional fixed factor, whose set is estimated by averaging the spatial patterns of 14 GCMs (Mendelsohn et al. 2000).

The model considers the damage of climate change for the following categories: agriculture, forestry, water resources, sea level rise, energy consumption, unmanaged ecosystems, and human health (diarrhea, vector-borne diseases, and cardiovascular and respiratory disorders). Impacts of climate change can be attributed to either the rate of temperature change (benchmarked at 0.04˚C per year) or the level of temperature change (benchmarked at 1.0˚C). Damages associated with the rate of temperature change gradually fade because of adaptation (Tol 2002a).

People can die prematurely due to climate change, or they can migrate because of sea level rise. Like all impacts of climate change, these effects are monetized. The value of a statistical life is set to be 200 times the annual per capita income. The resulting value of a statistical life lies in the middle of the observed range of values in the literature (Cline 1992). The value of emigration is set to be 3 times the per capita income (Tol 1995), the value of immigration is 40 per cent of the per capita income in the host region (Cline 1992). Losses of dryland and wetlands due to sea level rise are modeled explicitly. The monetary value of a loss of one square kilometre of dryland was on average $4 million in OECD countries in 1990 (Fankhauser 1994). Dryland value is assumed to be proportional to GDP per square kilometre. Wetland losses are valued at $2 million per square kilometre on average in the OECD in 1990 (Fankhauser 1994). The wetland value is assumed to have logistic relation to per capita income. Coastal protection is based on cost-benefit analysis, including the value of additional wetland lost due to the construction of dikes and subsequent coastal squeeze.

Other impact categories, such as agriculture, forestry, energy, water, storm damage, and ecosystems, are directly expressed in monetary values without an intermediate layer of impacts measured in their ‘natural’ units (Tol 2002a). Impacts of climate change on energy consumption, agriculture, and cardiovascular and respiratory diseases explicitly recognize that there is a climatic optimum, which is determined by a variety of factors, including plant physiology and the behaviour of farmers. Impacts are positive or negative depending on whether the actual climate conditions are moving closer to or away from that optimum climate. Impacts are larger if the initial climate conditions are further away from the optimum climate. The optimum climate is of importance with regard to the potential impacts. The actual impacts lag behind the potential impacts, depending on the speed of adaptation. The impacts of not being fully adapted to new climate conditions are always negative (Tol 2002b).

The impacts of climate change on coastal zones, forestry, tropical and extratropical storm damage, unmanaged ecosystems, water resources, diarrhoea malaria, dengue fever, and schistosomiasis are modelled as simple power functions. Impacts are either negative or positive, and they do not change sign (Tol 2002b).

Vulnerability to climate change changes with population growth, economic growth, and technological progress. Some systems are expected to become more vulnerable, such as water resources (with population growth), heat-related disorders (with urbanization), and ecosystems and health (with higher per capita incomes). Other systems are projected to become less vulnerable, such as energy consumption (with technological progress), agriculture (with economic growth) and vector- and water-borne diseases (with improved health care) (Tol 2002b). The income elasticities (Tol 2002b) are estimated from cross-sectional data or taken from the literature.

The FUND model is too large and complicated for the purposes of this paper. Therefore, we fitted a simple equation to the results. See Equation (5) in the main text.

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