University of Sussex
Economics

Working Paper Series

No. 83-2016

Distributional Implications of Geoengineering

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Abstract: Greenhouse gas emission reduction is a global public good. The main problem is underprovision, and the inequitable distribution of the impacts of excessive climate change. Geoengineering is a private good with externalities. Individual countries, and indeed medium-sized organizations and companies, can geoengineer unilaterally and impose their preferred climate on others. In this paper, I use the FUND model to illustrate the implications, comparing and contrasting efficient, optimal, and equitable solutions to emission reduction and geoengineering.

Key words: Climate change, geoengineering, efficiency, equity

JEL classification: Q54

1. Introduction

Through geoengineering, a single country can impose its preferred climate on the rest of the world. Different countries have different climate preference and thus a different demand for geoengineering. The impacts of climate change, geoengineered or not, are very diverse. This paper does two things. I quantify the implications of geoengineering for all countries in the world. I then derive the optimal level of geoengineering, and find progressive transfers to support that policy.

There is a substantial literature on the various technical options for geoengineering (Angel, 2006; Hoffert et al., 2002; Keith, 2000; Rasch et al., 2008; Vaughan & Lenton, 2011; Wigley, 2006) and its impacts on the climate (Bala, Duffy, & Taylor, 2008; Govindasamy & Caldeira, 2000; Heckendorn et al., 2009; Lenton & Vaughan, 2009; Matthews & Caldeira, 2007; Ricke, Morgan, & Allen, 2010; Robock, Oman, & Stenchikov, 2008). There are papers on the effects of geoengineering on optimal greenhouse gas emission reduction (Goes, Tuana, & Keller, 2011; Irvine, Sriver, & Keller, 2012; Moreno-Cruz, 2015), and on the governance of geoengineering (Barrett, 2008, 2009, 2014; Schelling, 1996; Urpelainen, 2012; Victor, 2008; Weitzman, 2015). These papers do not, however, have a detailed representation of distribution of the impact of climate change, and may thus misjudge the various stakes. There is also a literature on the ethics and desirability of geoengineering (Crutzen, 2006; Gardiner, 2011; Hartzell-Nichols, 2012; Heyward, 2014; Horton, 2014; Hulme, 2015; Jamieson, 1996; Liao, Sandberg, & Roache, 2012; Preston, 2011; Svoboda, 2012, 2015, 2016; Svoboda & Irvine, 2014; Tuana et al., 2012; Wong, 2014), but again these papers are largely void of empirical content, and may thus get the actual trade-offs wrong.

The paper proceeds as follows. In Section 2, I discuss the data and set-up a simple model. In Section 3, I discuss the distributional implications of climate change and geoengineering, and suggest a geoengineering policy that is both efficient and equitable. Section 4 concludes.

2. Data and model

Tol (2015) reviews the literature on the total welfare impacts of climate change, and conducts a meta-analysis. Twenty-seven estimates of the total welfare impact of climate change were taken from twenty-two studies. Various impact functions were fitted to the data. A piecewise linear function is, by far, the best fit to the global estimates. This function defines an optimal temperature, the climate at which average welfare is maximised. Welfare falls linearly if the temperature is above or below the optimum.

Ten estimates report regional detail, for six regions or more, and three have results for individual countries. The remaining fourteen only show a global total. A weighted regression of the regional estimates on the natural logarithm of per capita income and annual mean temperature, both regionally averaged, suggests that the welfare loss due to a 2.5°C warming is 1.2% of income less, with a standard deviation of 0.6%, for a country that is twice as rich and 0.4% less, with a standard deviation of 0.1%, for a country that is 1°C colder.

The function estimated using the regional results is used to impute national impact estimates. The national imputations are made to add up to the estimated regional and global totals by shifting the imputed values, that is, by changing the intercept.

Having thus obtained twenty-seven estimates of the national welfare impact of climate change, a piecewise linear impact function is fitted for each country. The global estimates suggest an optimum temperature of 1.0°C above pre-industrial temperature, or 0.2°C warmer than today's climate. The national optima are on average 0.3°C – half a degree colder than today – with a standard deviation of 1.3°C. This is if we assume that every country weights equally. If instead we weight every country by its 2005 population, the optimum temperature is on average 0.4°C with a standard deviation of 1.2°C. If we weight countries by their 2005 GDP, the average optimum is 1.7°C with a standard deviation of 1.5°C. The different results highlight that the world economy is concentrated in the temperate zone while the world population is concentrated in the tropics and subtropics. The large standard deviations highlight the diversity in the effects of climate change across the world.

The cold slope of the global impacts is -0.7 per cent Gross Domestic Product per degree Celsius (%GDP/°C), that is, there is a welfare loss equivalent to a 0.7 income loss for every degree Celsius of cooling. This is -7.1(5.4)%GDP/°C average over the countries, -6.1(5.2)%GDP/°C with population weights and -2.2(3.3)%GDP/°C with GDP weights. The warm slope is -1.4%GDP/°C for the global results: Welfare falls by -1.4%GDP for every degree warming. For the country results, the warm slope is -3.3(1.4)%GDP/°C. With population weights, this is -3.3(1.8)%GDP/°C and with GDP weights this become -1.7(1.8)%GDP/°C.

3. Results

Figure 1 shows the distribution of the impact of climate change. The top panel shows the Lorenz curves (Lorenz, 1905) for the welfare impact if the world would cool by 1, 2 or 3°C. The graph reveals that a 1°C cooling would lead to a welfare loss equivalent to an income loss of 5% or larger for 50% of the world population (in 2005), but a welfare gain for 7% of the people. Greater cooling does not shift the population numbers, but it does increase polarization.

The bottom panel of Figure 1 shows the Lorenz curves for the welfare impacts if the world would warm by 1 to 8°C. 92% of the world population would be worse off if the world would warm only 1°C. This goes up to 99% for 6°C. For a global warming of 1°C, nobody is worse off than the equivalent of a 10% drop in income. At 2°C, 5% of the world population are, and at 3°C, 49% of the world population suffer such a loss.

Figure 1 thus confirms that climate change would have very different impacts on different people, and that even modest climate change would be a serious concern for some.

Figure 2 plots the estimated temperature optimum for each country against its current temperature. Colder countries would welcome warming and warmer countries would welcome cooling. Note that the slope of the curve is only -0.1 – that is, for every 1°C increase in the current temperature, the desired temperature falls by 0.1°C.

Figure 3 shows the aggregate impact of climate change as a function of climate change. The impact is maximised at a temperature that is slightly below today's, but 0.5°C warmer than the pre-industrial average. Temperatures below pre-industrial times and above 1.1°C above pre-industrial would lead to a net loss of welfare. A warming of 2.0°C – the international policy target – would lead to a welfare loss equivalent to losing 0.8% of income.

The optimum in Figure 3 is not a Pareto optimum (Pareto, 1896). It is a Kaldor-Hicks optimum (Hicks, 1939; Kaldor, 1939): It maximizes total welfare, but compensation would be needed for those who lose out. I suggest compensating income transfers below.

Following Weitzman (2015), Figure 3 also shows the fraction of the world population who would prefer to keep the global mean surface air temperature below a certain level. Ten percent of the people would prefer a temperature of 0.1°C or more below pre-industrial times, fifty percent would prefer 0.2°C or less above pre-industrial, and ninety percent 1.7°C or less above pre-industrial

As geoengineering is so cheap, countries would prefer to geoengineer the climate to match the optima shown in Figure 2. There is obvious disagreement on the desired amount of geoengineering. Comparing Figure 2 to Figure 1 reveals that different degrees of geoengineering would have different effects on different countries.

While geoengineering may be cheap, geoengineering too much entails a cost, viz. the welfare loss from a non-optimal climate. I compute that cost using the Baker-Thompson rule (Fragnelli & Marina, 2010; Littlechild & Thompson, 1977), an operationalization of the Shapley value (Shapley, 1953). That is, as geoengineering lowers the temperature from the optimum for Canada, the highest, to the optimum for the United Kingdom, the second-highest, only the costs to Canada count. As the temperature is then lowered to the optimum for Switzerland, the third-highest, the costs to the Canada and the UK count and are measured relative to their respective optima. The same procedure is applied to the optimum temperature for Lithuania, the fourth-highest, for Latvia, the fifth-highest, and so on. The curve so derived can be interpreted as the cost curve of geoengineering. Its first partial derivative is displayed in Figure 4.

Using the same Baker-Thompson rule, I compute a benefit curve. Only Rwanda is prepared to pay to reduce the temperature from Uganda's optimum, the second lowest, to Rwanda's optimum, the lowest. Both Uganda and Rwanda are willing to pay to reduce the temperature from Mali's optimum, the third lowest, to Uganda's. And so on. The first partial derivative of the willingness to pay curve is shown in Figure 4.

The marginal costs curve meets the marginal benefits curve at 0.5°C above pre-industrial, a bit cooler than today. This happens to be China's preferred climate. Unsurprisingly (Coase, 1960), 0.5°C is the temperature that maximises total income (cf. Figure 3).

Figure 5 shows the distributional implications of this choice. Take the 2005 Lorenz curve of income as a starting point. Assuming countries need to be compensated if geoengineering pushes the climate below their optimum – the intuition behind Figure 3 – some countries gain, also net of the impacts of the climate deviating from their optimum. As shown in the top panel of Figure 3, these countries tend to be fairly rich already. Other countries, and particularly poorer countries, are doubly hit, first by a climate that is hotter than they want and second by having to compensate the countries that oppose the extent of geoengineering. For the poorest countries, this amounts to a loss of some 5% of an already low income.

Figure 4 was set-up based on the reasoning that countries would need to be compensated if geoengineering went too far for their taste. This is intuitive as geoengineering is a deliberate act – humans tend to emphasize harmful commission over harmful omission (Spranca, Minsk, & Baron, 1991). But one can also argue that countries should be compensated if geoengineering does not go far enough. By the Coase Theorem (Coase, 1960), this does not affect Figure 4. It does, however, affect the upper panel of Figure 5. This is shown in the bottom panel. The compensation flows in the opposite direction. Poor countries tend to gain, some quite a lot. Rich lose out, but only by a little.

4. Discussion and conclusion

I compute the Kaldor-Hicks optimal level of geoengineering, and show that is not a Pareto optimal level. There is no Pareto optimal level. I consider two sets of transfers – out of a great many – that compensate the losers of geoengineering to a global mean surface air temperature of 0.5°C. One set of transfers implicitly assume that people are entitled to unbridled climate change, and compensates those that would prefer less than globally optimal geoengineering from the gains of those that would like to see more. These transfer by and large flow from poor to rich. The other set of transfers implicitly assume that people are entitled to their favourite climate change, and compensates that would prefer more than globally optimal geoengineering from the gains of those that would like to see less. These transfers by and large flow from rich to poor. The latter solution thus reduces the disparity of income and may strike many as an acceptable compromise between efficiency and equity.

The analysis here is simple but it shows the basic inequities that come with any choice about geoengineering. There are obvious shortcomings. The analysis is static, but the problem dynamic. I consider geoengineering in isolation, omit a comparison to greenhouse gas emission reduction. I ignore uncertainty – about climate change, about its impacts, and about geoengineering itself. The welfare analysis is utilitarian with some hand-waving about distribution. All of this can and should be improved.

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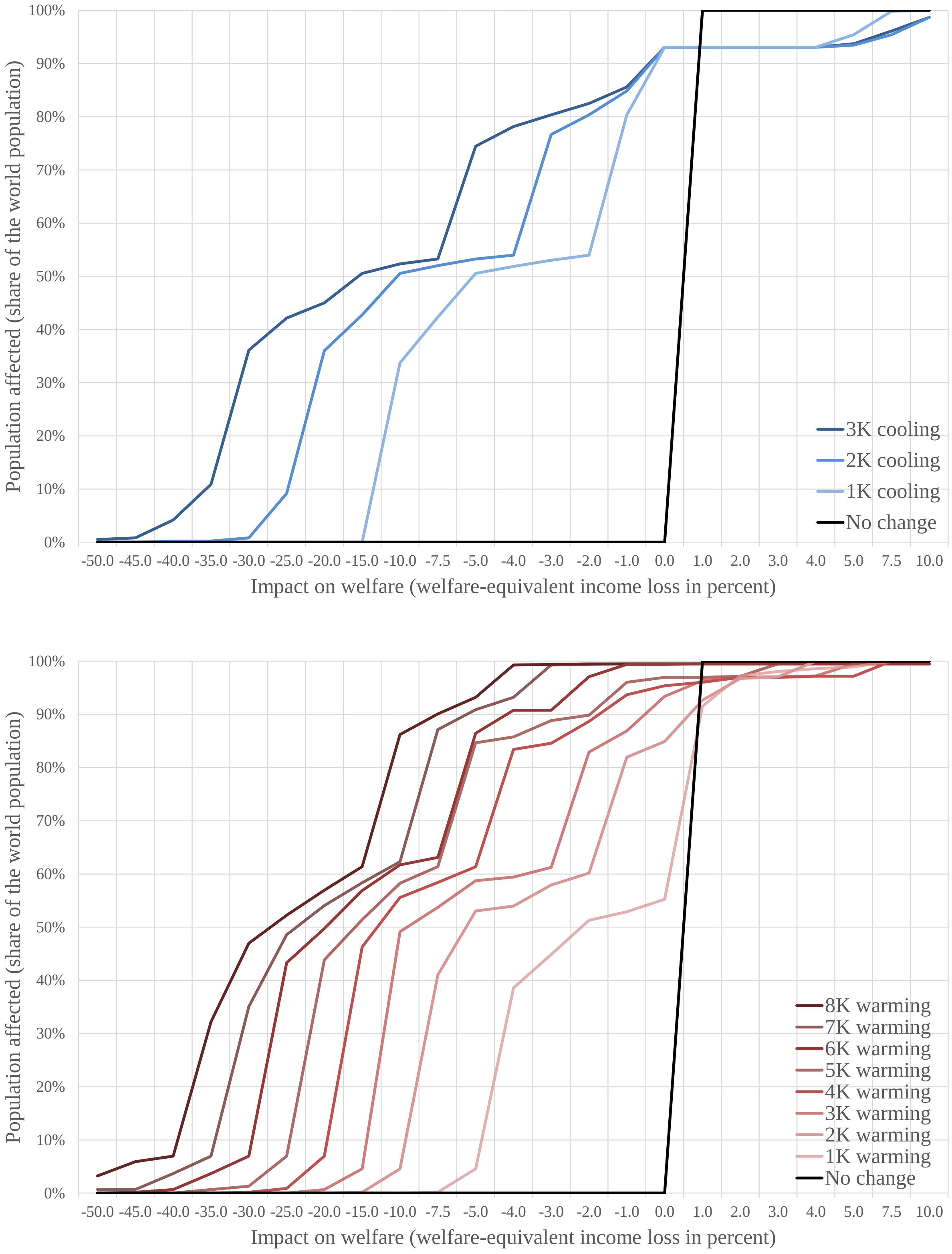

Figure 1. Lorenz curves of the impact for global cooling (top panel) and global warming (bottom panel).

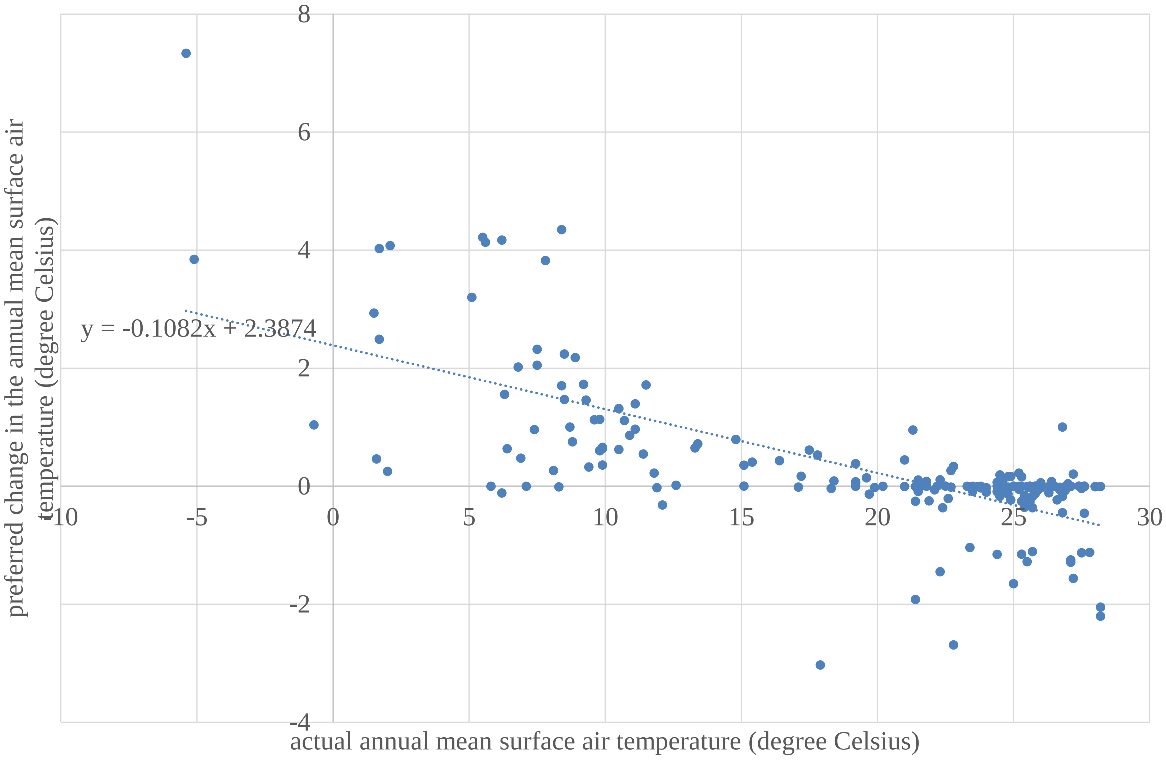

Figure 2. Preferred climate change as a function of the current temperature.

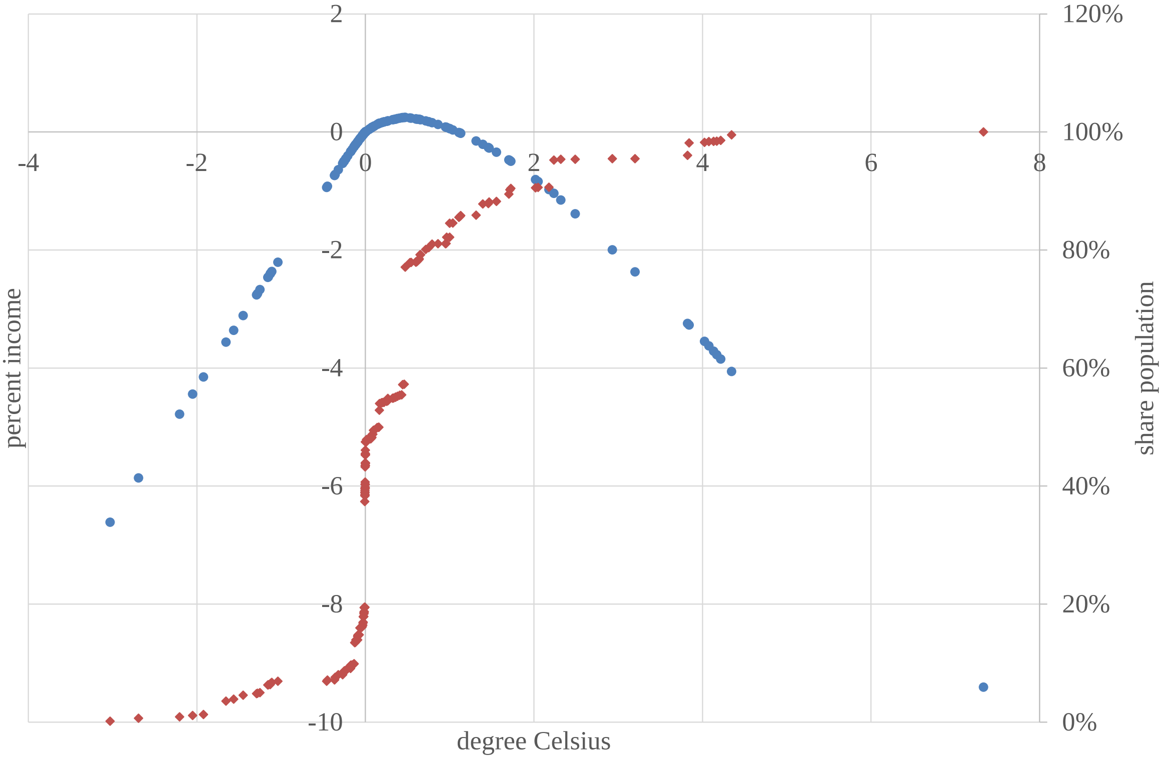

Figure 3. The global total impact of climate change as a function of the change in the global mean surface air temperature relative to pre-industrial times (blue dots; left axis) and the share of the world population who would prefer this temperature or cooler (red diamonds; right axis).

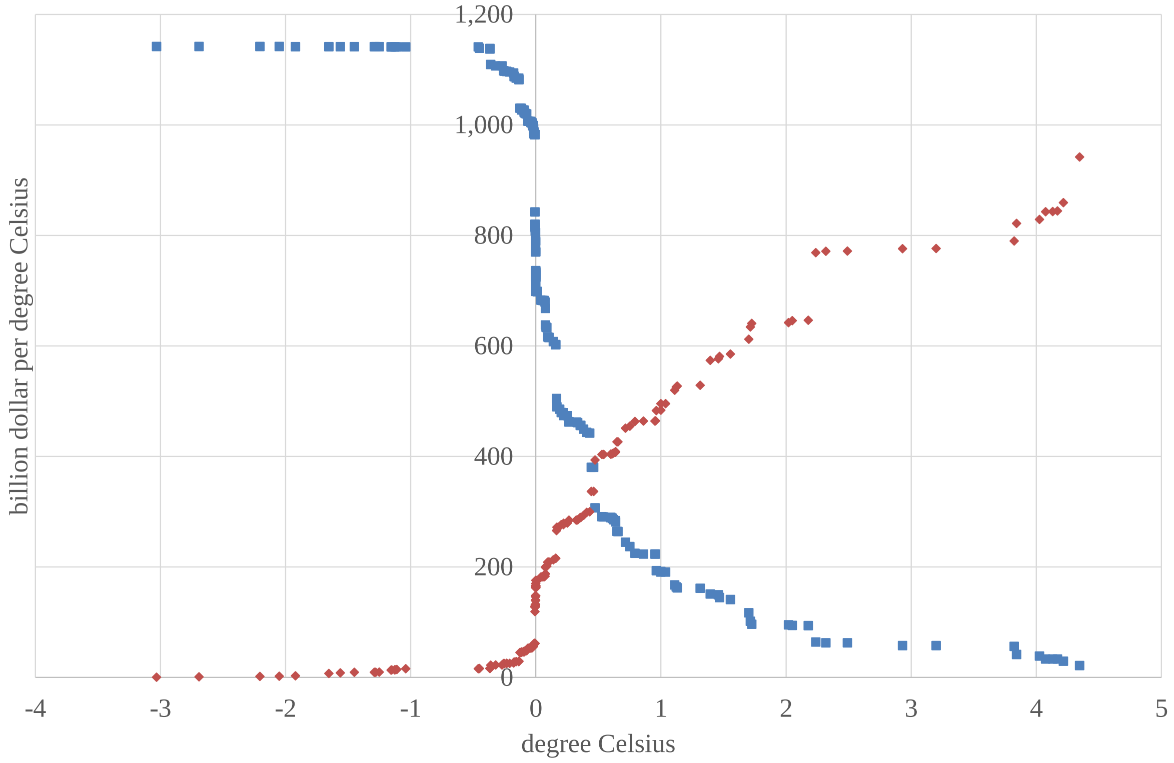

Figure 4. Marginal willingness to pay (blue squares) and marginal willingness to accept to compensation (red diamonds) for geoengineering.

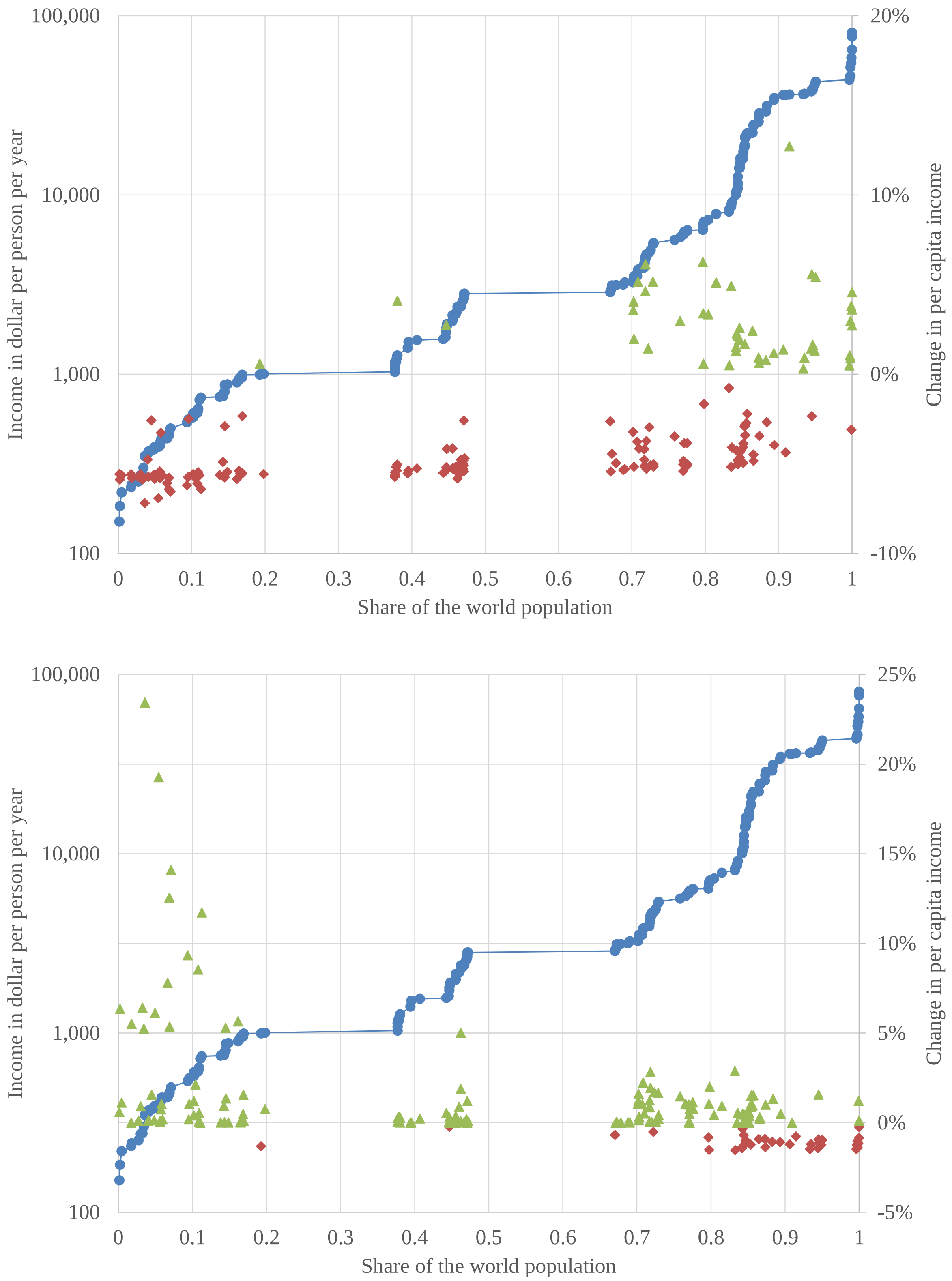

Figure 5. The Lorenz curve of income in 2005 (blue dots and lines; left axis) and the changes induced by climate change and compensation paid/received (increases in green triangles, decreases in red diamonds; right axis). The top panel compensates countries if geoengineering takes climate below their optimum, the bottom panel if the geoengineered climate is above the nation’s optimum.