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The Possibilities For Global Inequality and Poverty Reduction Using Revenues From Global Carbon Pricing *

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Abstract

Global carbon pricing can yield revenues which are large enough to create significant global pro-poor redistributive opportunities. We analyze alternative multidecade growth trajectories from 2015 to 2105 for major global economies with carbon tax rates designed to stabilize emissions in the presence of both continued country growth and autonomous energy use efficiency improvement. In our central case analysis, revenues from globally internalizing carbon pricing rise to 8% and then fall to 6% of gross world product. High growth in India and China reduces global inequality and poverty strongly over time, but important incremental redistributive effects can be achieved using global carbon pricing revenues. Taking into account both between-country effects and previous literature estimates of within-country effects, a global carbon tax alone tends to be regressive in its global incidence. However, if its revenues are redistributed globally via equal per capita transfers, in our central case the Gini coefficient for world income falls by about 3% and the share of the bottom decile rises by 81% on average from 2015 to 2105. The population living in poverty falls by 16% in 2015. Going further, global poverty could be eliminated entirely by 2015 according to our calculations if one third of global carbon tax revenues were redistributed directly to the poorest individuals.

Keywords: Carbon Pricing; Gini; Poverty Reduction; Millennium Development Goals.

JEL Classification: O19; Q56.

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1 Introduction

Past literature seems to have reached a consensus that price-type measures such as carbon tax and cap-and-trade are more advantageous in combating global warming than quantity-oriented methods such as those of the Kyoto and post-Kyoto protocols (see Shah and Larsen, 1992; Nordhaus, 2007; and Avi-Yonah and Uhlmann, 2009, among others). Furthermore and arguably, carbon tax is believed to be superior to cap-and-trade in combating global warming along crucial dimensions such as the size of potential revenues, efficiency, coping with uncertainty, prevention of corruption and ease of implementation (Nordhaus, 2007; Avi-Yonah and Uhlmann, 2009). The GHG abatement effects and economic consequences of a national carbon tax, including distributional impacts, have been extensively discussed in the literature (for instance in Hassett, Mathur and Metcalf, 2007, on the US; Brennera, Riddleb and Boyce, 2007, on China; Datta, 2010, on India; and Yusuf and Resosudarmo, 2007, on Indonsesia). Recently a global carbon tax has attracted increasing research attention since it is economically appealing as the most efficient way to equalize GHG abatement costs across countries.

A global carbon tax , and the uses of its revenues, could have important global redistributive effects. However, the literature is not clear about the incidence effects of global carbon pricing or the extent to which the revenues from such pricing could potentially reduce global inequality and poverty. Possible impacts on poverty are of special interest and are relevant to the achievement of the Millennium Goals. This paper addresses both the incidence of a global carbon tax and the possible distributional benefits from using carbon tax revenues for redistributive purposes. We find that the global incidence of a global carbon tax by itself is likely regressive. However, if a sufficient amount of the revenues are devoted to global redistribution, the disequalizing effect of the carbon tax can be neutralized. In the extreme, if all the revenues were used for redistribution global inequality and poverty could be significantly reduced.

We think it is reasonable suggesting that the revenues from a global carbon tax, administrated by a global agency, could be devoted, at least in part, to reducing global income inequality and poverty. In fact, doing so may be necessary in order to overcome resistance to a global carbon tax in many quarters. One idealized way to do that would be through an equal per-capita global transfer to individuals in all countries. We investigate the power of such a mechanism, and also examine more targeted measures aimed at reducing global poverty. It may be that such global initiatives are utopian, but what seems utopian today may become a realistic possibility in the future, and it is valuable to know what effects such ambitious initiatives would yield, as a point of comparison. Acknowledging the possible political impediments to worldwide redistribution, we compare the redistributive results of these global schemes with a perhaps more "realistic" approach in which revenues are used only for redistribution within national borders. We also ask what is the minimum that needs to be redistributed in order to offset the regressivity of a global carbon tax on its own.

In our main results we assume that global revenues from full carbon pricing are used to reduce inequality and poverty rather than for lowering other existing taxes. Our simulations cover the period 2015 to 2105. We assume a target of stabilizing emissions globally such that temperature does not rise 2°C above the preindustrial level before 2105, and global carbon pricing that meets targets for emission reductions to stabilize global temperature is implemented. As well, growth in national economies continues in the decades ahead consistent with emissions targets and taking the improvement in emissions efficiency of energy use into account.

We simulate both the between-country and within-country impacts of imposing carbon pricing from 2015 to 2105. Our results indicate that a global carbon tax on its own would be slightly increase between-country inequality in the next two decades, due to the lower emissions intensity of GDP in the highest income countries, but that beyond about 2035 the between-country effect would become equalizing. Incorporating literature-based estimates of within-country distributive effects, we find that the within-country incidence of a global carbon tax is regressive throughout our simulation period. Adding between-country and within-country effects together, on average over 2015-2105 a global carbon tax on its own would raise the world Gini coefficient by an average of 3.9%, reduce the share of the bottom decile of world citizens by 6.5% and increase the share of the top decile by 6.4%. Redistributing via an equal per capita global transfer largely reverses the effects, so that the Gini coefficient falls by 2.6%, the share of the bottom decile goes up by 81.1% and the share of the top decile rises by only 1.1%. The population living in poverty around the globe would fall by 16% in 2015 with this tax and transfer scheme.

To put our results further into context, we perform some further calculations. We ask how much of global carbon revenues would need to be allocated to the global transfer in order to eliminate global poverty in 2015. The answer is about one third. We also ask how much of the revenue would have to be devoted to the transfer scheme in order to offset the disequalizing effect of the carbon tax. The answer is 91.3% of the revenue would need to be so used in 2015, and that this percentage would fall to 51.8% by 2055, after which it would rise to 58.3% in 2105. Finally, we also compute the effects of redistributing the revenue only within countries, finding only a tiny equalizing effect of transfers in that case.

The remainder of the paper proceeds as follows. In Section 2 we present the business as usual (BAU) scenario without carbon pricing, and the growth and emissions patterns in the counterfactual where global temperature is prevented from rising more than 2°C above the preindustrial level before 2105, based on the analysis of Nordhaus (2010). We then determine the carbon prices required to implement the counterfactual, and the carbon pricing revenues thereby generated in Section 3, using our own analysis of the impacts of carbon tax on energy use and emissions. Section 4 sets out our data sources and methodology for the distributional analysis, and in Section 5 we present our main results. Finally, section 6 summarizes and concludes the discussion.

2 Base Case and Counterfactual Scenarios

The time period covered by our simulations is 2015 through 2105. Our base case is a business-as-usual (BAU) scenario without carbon emission reductions for the global economy between 2015 and 2105. This BAU scenario follows the base case of Nordhaus' RICE-2010 model (Nordhaus, 2010). Our counterfactual scenario implies an emissions target aimed at restricting global temperature change to less than 2°C by 2105. To be consistent with the BAU scenario, our counterfactual scenario also follows Nordhaus' RICE-2010 model , using his "limit to 2°C" case.

Three variables are at the heart of our analysis: growth in country/regional incomes, country and global emissions; and country and global population growth. Figure 1 sets out the paths of these three variables at the global level for the period 1960 to 2008. We see that Gross World Product (GWP) has risen more quickly than emissions or population since 1980 when the GWP data begin.

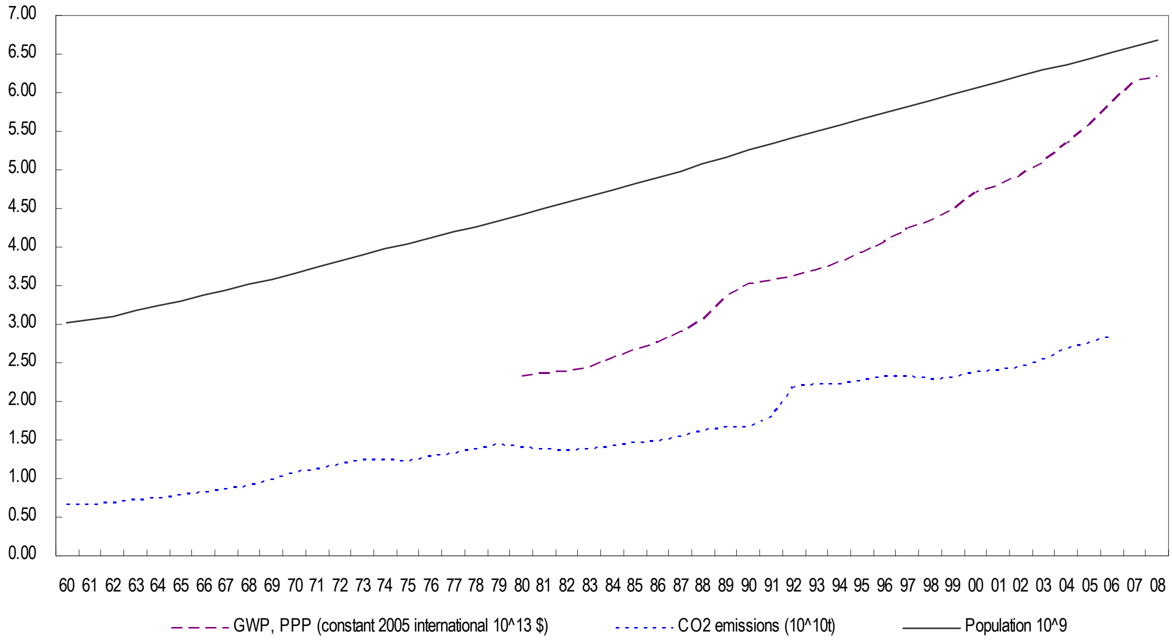
Purchasing Power Parity (PPP) GDP by country/region in the projections is given by a modified neoclassical production function used by Nordhaus. Total output for 12 regions[1] is projected by Nordhaus using a partial convergence model, and regional outputs are then aggregated to a world total. We use Nordhaus' adjusted projection GDP which accounts for climate damages in our BAU scenario. Population projections used by Nordhaus involve a simplified logistic-type specification in which the growth of population by region in the first decade is given and growth rates decline such that the total global population approaches a limit of 8.5 billion[2].

Emissions in these scenarios are projected using a series of geophysical equations described

[1]These 12 regions are the US, EU, China, Russia, Japan, India, Africa, Latin America, Eurasia, MidEast, Other Asia and Other High Income regions.

[2]Nordhaus (2008) notes that this projection is slightly below the middle estimate of the United Nations long-term projection (UN, 2004), but is calibrated to match the International Institute of Applied Systems Analysis (IIASA) projections (IIASA, 2007).

Figure 1: Historical Trajectories of GWP, Population and CO_2 Emissions, 1960 - 2008



Note: GWP is Gross World Product.

in Nordhaus (2008). His emissions projections are developed using different methods and more recent data than the IPCC SRES scenarios ("Special Report on Emissions Scenarios" for IPCC, 2000) [3].

The Nordhaus projections are for a 12-region classification. Since our later calculations of poverty impacts of carbon pricing are at a country level, we need to decompose the regionally aggregated data from Nordhaus. We assume that each country's shares of GDP, population and emissions within a region are constant at 2005 levels, the benchmark year in our analysis. Using this assumption, we decompose the regional aggregation in these scenarios into country-level projections for 189 countries.

Table 1 summarizes predicted global trajectories of our three central variables from 2015 through 2105 in both the BAU scenario and the counterfactual scenario in which global temperature increase is limited to 2°C up to 2105. Note that the population projection is the same in the two scenarios. GWP trajectories are similar across scenarios, except that from 2015 to 2085 abatement costs exceed the reduction of climate damage in the counterfactual by a small amount, so that GWP, which is net of climate damage and abatement costs, is slightly smaller than in the BAU. In 2105, however, the saving on climate damage has begun to dominate

[3]The Nordhaus emissions projections are toward the low end of the SRES range until the middle of the twenty-first century and then rise relative to some of the lower SRES scenario estimates.

abatement costs, so that GWP is projected to be higher in the counterfactual than in the BAU.

Table 1: BAU and Counterfactual Scenarios For GWP, Population and CO_2 Emissions Over 2015 - 2105 Implied by Nordhaus (2010)

	2005	2015	2035	2055	2085	2105
			BAU Scenario			
GWP after damages before abatement, $trill	55.20	80.75	145.90	224.44	362.94	473.41
Population (millions)	6407.27	7169.69	8374.06	8897.53	8905.66	8888.67
Total carbon emissions (GTC per year)	9.57	11.51	14.08	15.87	17.83	19.19
			Counterfactual Scenario			
GWP (net of damages and abatement, $trill)	55.20	80.66	145.40	222.52	361.73	478.41
Population (millions)	6407.27	7169.69	8374.06	8897.53	8905.66	8888.67
Total carbon emissions (GTC per year)	9.57	8.73	7.56	3.38	0.27	0.17

Note: i) GWP is Gross World Product.
ii) In the counterfactual scenario, global temperature increase is limited to 2°C or less up to 2105.
iii) $trill refers to trillion 2005 PPP dollars.
iv) GTC refers to gig metric tonnes of carbon.

3 Revenues From Carbon Pricing in Counterfactual Analysis

We use the counterfactual scenario set out above to evaluate the potential redistributive impacts of full global carbon pricing schemes aimed at internalizing the global externality from carbon emissions. A single global price for all emissions of carbon dioxide and other greenhouse gases, to be administrated by a single global agency collecting the revenues, that is effectively a global carbon tax, is assumed. Revenues are assumed to be deployed for alternative global redistributive purposes by this global agency.

A key element in our calculations of redistributive impacts is the level of carbon prices needed as these levels are critical in determining revenue. A variety of carbon pricing assumptions are adopted in the literature as part of the global policy regime needed to achieve various emissions targets (Stern, 2007; Nordhaus, 2008; Boyce and Riddle, 2009, among others). These range from tens to thousands of dollars per tonne of carbon. Here, we calculate the carbon pricing needed globally to achieve a bound on global temperature change of 2°C by 2105. This gives us carbon prices for our central cases. Our calculation of carbon pricing revenues departs from Nordhaus (2008) in two important ways. We employ the notion of price elasticity of demand for fossil fuels to determine the carbon pricing in a direct manner, while Nordhaus (2008) uses constant elasticity of substitution in consumption instead. Second, our calculations capture the move into renewable energy sources in autonomous energy efficiency improvements but this is absent in Nordhaus (2008).

The price elasticity of demand for energy is key in calculating our level of carbon pricing, and we use literature based estimates of the elasticity of the demand for fossil fuels in our calculations. Most of these estimates can be grouped into one of three classes: near zero, near negative unity (minus one) or around minus one-half (Lipow, 2010). Komanoff (2010) estimates separate demand price-elasticities by energy sources, - 0.7 for electricity, - 0.4 for gasoline, - 0.6 for jet fuel, and - 0.5 for other fuels. US shares of consumption across these energy categories are roughly 40%, 21%, 4% and 35% (Komanoff, 2010), and this yields an average elasticity across sources of - 0.55. We use - 0.5 as our central global price elasticity of demand for fossil fuels. We assume this elasticity is constant over time and over the interval of possible demands, $(0, +\infty)$. As a result, each projection year assumes a constant own-price elasticity.

Another key element in our calculations of carbon pricing needed to achieve targeted emission reductions is the likely energy efficiency improvement over time either from behavioral changes in energy consumption or technology upgrading. The International Energy Agency (IEA) has issued three reports on worldwide energy efficiency. According to the latest (IEA, 2008), the energy efficiency improvement achieved for 16 IEA countries[4] over the period 1990 - 2005 averaged only 0.9%. We assume that this rate of improvement continues and remains constant after 2005.

Developing and transitional economies experienced larger energy efficiency improvements over the same period. For instance, in China, the index of Total Final Energy Consumption per Unit of GDP fell from 100 in 1990 to 40 in 2005, averaging roughly a 4% energy efficiency improvement per year. Similarly, India also saw high average energy efficiency improvements of roughly 2.9% per year during the same period. Data for other developing countries outside the IEA are limited. We assume a 3% energy efficiency improvement rate for the rest of the world except the 16 IEA countries included above. These 16 IEA countries consumed around 50% of world primary energy in 2005 (UN, 2007, table in Box 1 on page 10). Combining these two groups yields an estimate of 2% worldwide energy efficiency improvement per year. In our baseline analysis, we assume this same energy efficiency improvement factor applies for both the BAU and the counterfactual targeted to achieve a 2°C temperature change cap. We then relax this assumption in sensitivity analysis.

A further element is backstop technology progress including carbon absorption through sinks, capture and storage; and introduction of other renewable non-carbon energy sources as substitutes for fossil fuels when carbon prices are high. This element is implicitly expressed

[4]They are Australia, Austria, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, New Zealand, Norway, Sweden, Switzerland, UK, and US. They comprise the greater part of the OECD in terms of population and GDP.

in Nordhaus' geophysical and industrial emissions equations (Nordhaus, 2008 and 2010). It plays a crucial role in explaining how quite small emissions could sustain the world economy toward the end of the simulation period, such as from 2085 to 2105. Here we model this element explicitly, using a constant annual rate of emission reduction per unit of energy, λ, assumed equal to 4%.

Given the assumed values of E_τ and E^*_τ, we solve for D_τ and D^*_τ which are fuels demands at time τ in BAU and counterfactual cases respectively. Using a price elasticity, efficiency improvement factors and technological progress in carbon capture, we next calculate the carbon price levels and revenues needed to achieve emissions reductions consistent with a global temperature change target of 2°C. The base date is t_0 and the date for target temperature change is τ. Emissions both at time t_0 and τ for the BAU and counterfactual cases are as in Table 1. We denote BAU and counterfactual emissions as E_τ and E^*_τ respectively. Energy efficiency improves from f_{t_0} at time t_0, to $f_{t_0}[e^{\delta_i(\tau-t_0)}]$ at time τ, where $\delta_i (i = 0, 1)$ denotes the global efficiency improvement factor assumed in both the BAU ($i = 0$) and counterfactual ($i = 1$) cases. In addition, the emissions deflation factor due to backstop technology progress is $e^{-\lambda(\tau-t_0)}$. We further assume a conversion from fossil fuels to carbon emissions coefficient, denoted by c, which is fixed over time.

We thus have

$$
\begin{aligned}
E_\tau &= D_\tau \cdot f_{t_0}\left[e^{\delta_0(\tau-t_0)}\right] \cdot c, &(1)\\
E^*_\tau &= D^*_\tau \cdot f_{t_0}\left[e^{\delta_1(\tau-t_0)}\right] \cdot c \cdot e^{-\lambda(\tau-t_0)}, &(2)
\end{aligned}
$$

After solving D_τ and D^*_τ, we can then use a price elasticity of demand estimate to calculate the carbon prices needed to achieve the given target.

We use an equivalent carbon tax (ECT) for carbon based fossil fuels energy sources, since there is only an elasticity of demand of fuels, but no carbon demand elasticity as such. We denote the incremental component of the price of fossil fuels (effectively a tax) due to full global carbon pricing as r_E, giving

$$P^*_\tau = (1 + r_E)P_\tau, \tag{3}$$

where P^*_τ and P_τ are the prices of fuels at τ for the counterfactual case (incorporating carbon pricing) and the BAU case respectively. The elasticity of demand for fossil fuels at time τ is given by

$$\frac{(D^*_\tau - D_\tau)/D_\tau}{(P^*_\tau - P_\tau)/P_\tau} = \eta_\tau. \tag{4}$$

As the efficiency improvement in the counterfactual case is the same as in our BAU case (i.e., $\delta_1 = \delta_0$), substituting (1) through (3) into (4) gives

$$r_E = \frac{E_\tau^* e^{\lambda(\tau - t_0)} - E_\tau}{\eta_\tau E_\tau}. \tag{5}$$

In later sensitivity analysis, we relax the similar country efficiency improvement factor treatment and let $\delta_1 > \delta_0$. This implies the value of the elasticity is equal to

$$\eta_\tau^e = \frac{E_\tau - E_\tau^* e^{\lambda(\tau - t_0)} \cdot e^{-(\delta_1 - \delta_0)(\tau - t_0)}}{E_\tau - E_\tau^* e^{\lambda(\tau - t_0)}} \times \eta_\tau. \tag{6}$$

and substituting this elasticity into (3) gives

$$r_E^e = \frac{E_\tau^* e^{\lambda(\tau - t_0)} - E_\tau}{\eta_\tau^e E_\tau}, \tag{7}$$

where r_E^e is the incremental fossil fuels price from carbon pricing in the case using different country energy efficiency improvement factors.

Finally, the global full carbon price, Γ, measured as a PPP 2005 International \$/metric tonne of CO_2 can be calculated by

$$\Gamma = \beta \times r, \tag{8}$$

where β is the fixed coefficient relationship between gallons of fossil fuel and metric tonnes of CO_2; and r takes on the alternatives of r_E and r_E^e for uniform and country different energy efficiency improvement cases. Using an average price of gasoline over the last 10 years of $\$2/gallon$ (EIA, 2010), yields an estimated value of β (see also Komanoff's (2010) CTC Carbon Tax Model).

Our method of determining levels of carbon pricing deviates from Nordhaus (2008 and 2010), even though our emissions data, in both BAU and counterfactual cases, are the same. Nordhaus' carbon pricing schemes yield carbon revenues less than 2% of Gross World Product (GWP) on average. These imply a fossil fuels price elasticity of demand that is seemingly very much larger than estimates in the empirical literature.

The elasticity method set out above yields a carbon price for global emissions each period assuming all emissions are included and treated equally. Table 2 presents our calculations of carbon prices at different dates. These imply that, over the next 100 years, carbon prices would rise gradually from \$85/TCO_2 in 2015 to \$1061/TCO_2 by 2085, after which they would decline to \$819/TCO_2 in 2105.

The revenues raised by the carbon pricing schemes are then assumed to be transferred to lower income countries in alternative ways. Table 2 suggests that revenues from carbon pricing

Table 2: Full Global Carbon Pricing and Associated Revenues

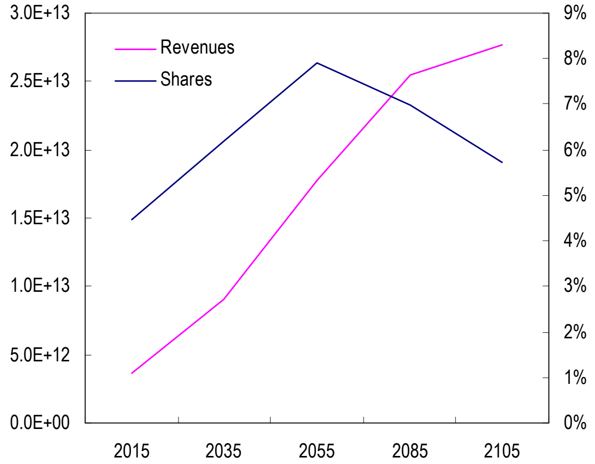
	2015	2035	2055	2085	2105
Carbon Pricing	85	104	200	1061	819
Revenues	3.60×10^{12}	9.01×10^{12}	1.77×10^{13}	2.55×10^{13}	2.76×10^{13}
Shares of GWP	4.5%	6.3%	7.9%	7.0%	5.7%

Carbon pricing, effectively carbon tax rates are in $2005(PPP) per metric tonne of CO_2. Revenues are in 2005 PPP dollars. Shares refer to the ratio of revenues to the projected GWPs in respective years. 22 smaller countries are dropped in our dis-aggregating regional projections of Nordhaus' (2010) RICE-2010 model into country level data because of missing data in the benchmark year of 2005.

in our central case are 4.5% of GWP in 2015 rising to a peak of 7.9% in 2055 and declining then to 5.7% in 2105.

Figure 2 indicates that the revenues in absolute values increase over time from 2015 to 2105, despite the fact that the revenue share of GWP peaks at 7.9% in 2055. This is for two reasons. On one hand, the difference in carbon emissions between the BAU and counterfactual scenarios is relatively stable from 2055 to 2105, which prevents revenues over these years from growing sharply. On the other hand, GWP continues to grow over the period between 2055 and 2105, while carbon emissions are curtailed to lower levels. We thus see decreases in carbon tax revenue in relation to GWP from 2055 to 2105.

Figure 2: Revenues from Carbon Pricing in the Central Case



Note: Revenues are carbon pricing revenues in absolute values.
Share is carbon pricing revenues as percentage of GWP.

4 Redistribution Schemes and Methods of Measuring Global Distributional Impacts

4.1 Data Sources for Redistribution Schemes

For counterfactual analysis of the potential impacts of full global carbon pricing on global inequality and poverty, we need data on current emissions, population, global income distribution, and revenues from carbon pricing over the period 2005 to 2105, with an international poverty line specified. Our benchmark year is 2005.

For the benchmark year, our GDP, carbon emissions and population data at country level all draw on the World Bank's World Development Indicators (WDI) database. The WDI table has 211 countries in total. We only use 189 countries, dropping 22 due to missing data in the benchmark year.

Beyond the benchmark year, projected GDP (in $2005PPP), carbon emissions and population data at the 12 region level follow Nordhaus (2010). Under the assumption that each country's shares of GDP, emissions and population within its region are fixed at the levels of the benchmark year, we can generate country level data. The aggregate data does not include the 22 countries that were dropped.

Using data on country emissions for each projection year, we allocate the tax burden from carbon pricing reflected in the global revenues shown in Table 2 to each country according to its share of global emissions. Ideally, to quantify redistributive impacts here, we need data on global and within-country income distribution over the time period 2005 to 2105. While recent and comprehensive data on poverty and income distribution are available from the World Bank, we have no basis for projecting future changes in national income distributions other than those caused by our tax/transfer scheme. [5] However, the BAU and counterfactual projections do provide a path for each country's GDP per capita from 2005 to 2105. This provides a basis for projecting changes in income inequality between countries, which is the most important component of global income inequality.

Despite the above difficulties, we can generate projections of both global income inequality in the BAU and counterfactual scenarios. To project changes in inequality between countries we use per capita GDP (in 2005 PPP dollars) as a proxy for per capita personal income. This reflects the non-availability of personal income projections for 2015 - 2105. Using GDP and

[5] The information we need on income distribution is available through the World Bank's World Development Indicators. Information on poverty was obtained through PovcalNet, a product of the World Bank's Development Research Group. It is an interactive computational tool that estimates the extent of absolute poverty in the world. It can be accessed freely via http://iresearch.worldbank.org/PovcalNet.

population projections from Nordhaus (2010) taken to the country level, we project the proxy income for each country. Within countries we fit a lognormal distribution for income in 2005 on the basis of World Bank data, as explained below. For later years we assume that these within-country distributions only change by scale, that is relative inequality of income measured before our tax/transfer schemes remains the same as in 2005 within each country. To obtain projections of the global income distribution after our tax/transfer schemes apply we assume in this section, and in the first part of the next section, that emissions are proportional to income within countries. The ratio of emissions to income is, however, allowed to vary across countries according to the Nordhaus projections along the BAU and counterfactual paths.

4.2 Redistribution Schemes

We use two revenue redistribution schemes in our counterfactual analysis. The first redistributes equally on a per capita basis all over the world. This is the simplest approach. Our later calculations and analysis mainly focus on this alternative. Our second scheme allocates a larger share of revenues on a global scale to the extreme poor than in the equal per capita scheme. The extreme poor are those living below the World Bank's updated international poverty line which is discussed in section 4.3. Using this scheme, we seek to find whether it is possible to move all the extreme poor above the poverty line by 2015 using only a carbon pricing and transfer scheme, and how large a share of revenue needs to be dedicated to the extreme poor in order to realize this ambitious goal.

4.3 Methods of Computing Inequality and Poverty Measures

We analyze the effects of a global carbon tax and associated transfer schemes on inequality and poverty both within countries and on a global scale.

In investigating these effects , we focus on changes in the global Gini coefficient, the shares of the top and bottom deciles, and the number of people below the poverty line.[6]

As explained below, our analysis of impacts on the Gini coefficient, both globally and within countries, is independent of any assumption about the shape of the income distribution if emissions are assumed proportional to income within countries and an equal per capita transfer is used. We therefore begin with this case before moving on to aspects that require specifying the shape of the distribution, either within countries or globally. These aspects

[6] Since the Gini coefficient is less sensitive to the tails than to the middle of the distribution, in order to picture the impact on overall inequality it is good to supplement it with the shares of the top and bottom deciles. The bottom decile is also of special interest given the focus of the Millennium Goals and much development policy on the lower tail.

include allowing emissions, and carbon tax burdens, not to be proportional to income within countries, and calculating decile shares and poverty measures.

4.3.1 Gini Coefficients

The global Gini coefficient can be decomposed into within country, between country, and remainder terms as follows (see e.g. Mookherjee and Shorrocks, 1982):

$$G = \sum_k \upsilon_k^2 \vartheta_k G^k + \frac{1}{2} \sum_k \sum_h \upsilon_k \upsilon_h \left| \vartheta_k - \vartheta_h \right| + R, \tag{9}$$

where G^k is the Gini coefficient within country k, υ_k is country k's proportion of global population, ϑ_k is its mean income relative to that of the whole world, and the remainder' term R reflects the interaction effect due to overlaps between the income distributions in different countries. We project future changes in global income distribution by making separate projections for the three decomposition components. We use 2002 as our calibration year. According to Milanovic (2009), this is the latest year having household survey data and a reliable global Gini coefficient estimate.

As explained above, we assume that relative inequality of income before the tax/transfer scheme, and therefore the Gini coefficient, stays fixed over time within countries. The WDI database provides Gini coefficients for 143 of our 189 countries. Gini coefficients for the 46 countries with missing values are assumed equal to the arithmetic average. This procedure gives us the first term in equation 9 for income before the tax/transfer scheme. The second term in equation 9 corresponds exactly to the "international" or Concept 2 inequality of Milanovic (2005, 2009). That is, it is the global Gini coefficient one would obtain if there were zero inequality within countries. Finally, the value for R can be calibrated using the Gini coefficient for the global income distribution of 0.7 in 2002 found by Milanovic (2009) using 2005 PPP exchange rates. We further assume that the value for R stays fixed over the projection years. Equipped with values for the "within" term and R, we are able to specify the global Gini coefficients of income before the carbon tax and transfer for each projection year.

To compute within-country Gini coefficients for income after the carbon tax and transfer we use different procedures depending on whether the within-country incidence of the carbon tax is modeled. If within-country distributional impacts of the tax are not modeled, its burden is proportional to income within each country. We begin by discussing this case. We denote the mean income of country k as $\bar{y}_k$, the effective carbon tax rate as a proportion of income in country k as τ_k, and the per capita transfer as D. Note that although the carbon tax rate is the same in all countries, τ_k differs since carbon use per dollar of income is different across countries. In contrast D is the same everywhere. Since we are assuming, for the moment, that carbon use is proportional to income *within* countries, the carbon tax and transfer scheme is equivalent to a proportional income tax combined with the transfer D in each country. The impact on the Gini coefficient for a country is intuitive. The tax reduces after-tax income but has no impact on the Gini coefficient, or any other measure of relative inequality for a single country, because the impacts on income are equi-proportional. On the other hand, giving each person the equal absolute transfer D reduces proportional income differences between people, causing a drop in the Gini coefficient. The fall in the Gini coefficient is in inverse proportion to the change in the mean from its value without the transfer, $(1-\tau_k)\bar{y}_k$, to $(1-\tau_k)\bar{y}_k + D$. We get the following relationship between the original Gini, G^k, and the Gini for income after the tax and transfer scheme, G'^k: [7]

$$G'^k = G^k \frac{(1-\tau_k)\bar{y}_k}{(1-\tau_k)\bar{y}_k + D}. \tag{10}$$

Thus, we have a procedure for projecting global Gini coefficients for income along the Nordhaus BAU path, and also along the counterfactual path with the carbon tax and transfer schemes we will model in the case where the carbon tax has no within-country incidence effects. The methods can be extended to allow carbon tax incidence effects within countries given estimates of how the carbon tax burden varies with income, and how income is distributed, within each country. In the next section we explain how we estimate carbon tax burdens at the decile level within countries. The distributional assumption is that income before the tax and transfer has a lognormal distribution in each country. These distributions are parameterized using our estimate of the countrys mean income, and its Gini coefficient of income from the World Banks WDI database.[8] Global distributions of income both before and after the tax and transfer schemes can be estimated by creating samples within countries, drawn from the specified country-level distributions, and weighting them by country population. The procedure followed in the next section forms a sample made up of 10 individuals representing deciles in each of 189 countries, for a global sample of 1890 individuals.

[7]Equation 10 can be derived using the fact that the Gini coefficient equals one half the mean difference (between individual incomes taken pairwise), divided by the mean (see e.g. Cowell, 1977). A proportional tax reduces the mean difference and the mean by the same fraction, with no net effect on the Gini coefficient. The transfer, on the other hand, has no effect on the mean difference, but increases the mean. The transfer therefore reduces the Gini coefficient in inverse proportion to the change in the mean, as seen in (10).

[8]The lognormal distribution is fully specified by the mean and variance of log income. The variance of log income can be computed from the Gini coefficient (see Cowell, 1977), and the mean of log income can then be derived from the variance of logs and the arithmetic mean.

4.3.2 Decile Shares and Poverty Measures

Above we have explained how the global Gini coefficient can be computed, with and without our carbon tax and transfer schemes. But we also want to know the corresponding shares of the top and bottom deciles plus the absolute poverty levels through time. In order to get this additional information we need complete world distributions of income for each run, year, and income measure. One way to get these world distributions is to specify a distribution within each country and sample from those distributions to build up a global sample, as we do when investigating the impact of within-country carbon tax incidence (see above). However, for our main results we prefer to work with a continuous global distribution, which avoids problems associated with the lumpiness in a finite sample. These latter problems are more significant when focusing on details of the top and bottom tails of the distribution than when computing the Gini coefficient.[9]

In quantifying top and bottom deciles and absolute-poverty impacts from carbon pricing, we assume a lognormal distribution for global incomes. Denoting income as w, we thus assume it has the density function

$$g(w) = \frac{1}{\sqrt{2\pi}\sigma w} e^{-\frac{(\ln w - \mu)^2}{2\sigma^2}}. \tag{11}$$

Given a world population, P, the population N_h with income no higher than h is

$$N_h = P \int_0^h \frac{1}{\sqrt{2\pi}\sigma w} e^{-\frac{(\ln w - \mu)^2}{2\sigma^2}} dw. \tag{12}$$

To fully characterize this normalized function requires two parameters, μ and σ. In our calculations, we generate a world population, P, and GWP, I, in scenario projections, giving the world average income $\frac{I}{P}$ for each year under study. In addition, we also have a global Gini coefficient for each time period. Using these data, we are able to parameterize the function (11) applying the following two formulas for lognormal distributions (see Kemp-Benedict, 2001; also see Deaton, 2008):

$$\sigma = \sqrt{2}\Phi^{-1}\left[\frac{Gini + 1}{2}\right], \tag{13}$$

$$\mu = \ln\left(\frac{I}{P}\right) - \frac{\sigma^2}{2}, \tag{14}$$

[9] See Davies and Shorrocks (1989), whose results imply that the Gini coefficient is remarkably robust with respect to the kind of grouping error discussed here. Note that the lumpiness problem that may nevertheless obscure ones view of the detailed shape of the distribution, especially in the tails, is not reduced as much as one might think in going to the global sample. Deciles from China and India each represent almost 2% of world population, making them "lumpy" even at the global level.

where $\Phi^{-1}[\cdot]$ is the inverse cumulative distribution function of the standard normal.

In quantifying absolute poverty impacts, we next set the poverty line. We use a criterion of \$ 1.25 in 2005 PPP per day suggested by the World Bank as the international poverty-line (Chen and Ravallion, 2008). This must be translated into an Equivalent Poverty Line, w_c, in terms of GDP per capita. Chen and Ravallion (2008) document that with the \$1.25 poverty-line, 1.4 billion people were in poverty in 2005. As we have world population P, and values of μ and σ for 2005, we can then solve for $\ln w_c$ mapping into 1.4 billion in-poverty people using the inverse of equation 12. This critical value $\ln w_c$ is equivalent to the \$ 1.25 poverty-line. For simplicity we assume that the Equivalent Poverty Line remains constant through time.

Equipped with distribution parameters and our Equivalent Poverty Line, we quantify absolute poverty reduction due to carbon pricing and revenue redistribution. Firstly, in our BAU scenario, we substitute values of μ , σ and $\ln w_c$ for each year into equation 12 to find the population in poverty without carbon pricing. Secondly, with carbon pricing and revenues redistribution, we re-calculate GDP per capita for each country and produce the new Gini and mean income accordingly. Then we repeat the first step, and substitute $\ln w_c$ and the new μ and σ into equation 12 to find the population in poverty in our counterfactual scenario. The difference in the populations in poverty in these two scenarios (in-poverty population at first step minus values from the second step) reflects the impact of the carbon tax/transfer scheme in global absolute-poverty reduction.

5 The Potential Global Redistributive Impacts of Global Carbon Pricing

We next report results on the potential redistributive impacts of global revenue redeployment from full global carbon pricing. Our central carbon pricing scheme collects revenues as specified in Table 2 which are the effective carbon tax burdens allocated to each country according to its shares of global emissions at various dates. These results assume that the global price elasticity of demand for fossil fuels is -0.5, and the annual energy efficiency improvement factors for both BAU and counterfactual cases are all 2% per year for all countries. GDP, population and emissions growth trajectories follow Table 1.

5.1 Inequality Reduction Potential Assuming Proportional Within-Country Incidence of Carbon Tax

We analyze global redistribution impacts in terms of global Gini coefficients and income shares of the top and the bottom deciles. In this subsection we assume that carbon tax incidence is proportional to income within countries. Because the ratio of emissions to income varies across countries the carbon tax has between-country incidence effects, however. Those are reported in Part I of Table 3 which shows changes in Gini coefficients and the world top and bottom decile shares that come from the carbon tax alone. Part II of the table goes on to also include the effects of redistributing all of the global carbon tax revenue in the form of equal per capita transfers. Both between-country and within-country effects of the transfer are captured.

Part I of Table 3 shows that the between-country incidence of the carbon tax is initially regressive according to the measures reported, but becomes roughly neutral by 2035 and thereafter increasingly progressive. That is, in 2015 the carbon tax by itself increases the world Gini coefficient for after-tax income, raises the top decile share and reduces the bottom decile share. After 2035 these effects are reversed.

The progressivity or regressivity of the carbon tax alone is determined here by three effects: the impacts on GDP of abatement costs, carbon tax payments, and climate damage. Initially, there is little change in climate damage in the counterfactual relative to the BAU. The ratio of emissions to GDP is below average in the top quintile of countries by population, tending to make both carbon tax payments and abatement costs a smaller share of income for the richest countries, producing an overall regressive impact. As time goes on, the reduction of climate damage tends to buoy GDP more for lower income countries since on average they lie in less temperate zones and suffer more from climate change. At the same time, the differences in emissions relative to GDP across countries ranked by income decline considerably. This is partly due to our higher assumed rate of energy efficiency improvement outside the 16 IEA countries (see Section 3), but it also related to differences in growth rates. India and China, which initially have above-average emission to GDP ratios, both rise in the global income distribution, which moves considerable carbon tax burden up the global income ladder.

Part II of Table 3 presents the results when the equal per capita transfer is introduced along with the carbon tax. Note first that in the BAU global inequality would fall considerably over time due to above-average projected rates of growth in GDP per capita in many low and middle income countries, of which China and India are quantitatively the most important. The Gini coefficient falls by 25% in the BAU case over the projection period, from 0.6825 in 2015 to 0.5114 in 2105. The bottom decile share increases by 2.4 times and the top decile share decreases by

31%. These results suggest that in the long-run growth in the developing economies will be a very powerful equalizing force. Indeed, on the basis of the projections reported in Table 3 by 2105 that force will be much stronger than the equalizing impact of a carbon tax and transfer scheme. However, that force takes time to build up, whereas the carbon tax and transfer would have an effect that is immediate and very substantial in the bottom tail of the distribution. The tax and transfer scheme would reduced the global Gini coefficient by 4.2% in 2015 and would raise the share of the bottom 10% of world citizens by 120.4%, according to our calculations. Also note that in 2105 we project the tax and transfer scheme would still increase the share of the bottom 10% by 45.6% compared to the BAU.

It is also instructive to ask how much of global carbon tax revenue would need to be redistributed in order to make sure there is no increase in global inequality. As we have seen, even when there are no within-country distributive effects of the carbon tax, in the first few decades of our simulation the carbon tax by itself increases global inequality a little. This is seen in a decline in the share of the bottom decile and a rise in the Gini coefficient. Offsetting those changes entirely in 2015 would require that just 6.9% of global carbon tax revenues be devoted to an equal per capita global transfer. [10]

The solid lines in Panel A to C of Figure 3 plot the changes in Gini coefficient, bottom decile share and top decile share across time periods. Columns with a "Carbon Pricing" heading in Table 3 present the results for the three inequality indicators after carbon pricing and transfer specified in our central scheme. In Figure 3, they are plotted in dot-dash lines, with legends showing the elasticity of 0.5 used in brackets. Carbon pricing can play a major incremental role in global income equalization in addition to economic growth, driving increases in the bottom decile shares and decreases in the Gini and top decile shares. Among these three indicators, carbon pricing has the larger impacts on the bottom decile share, and a slight downward shift in the top decile share.

Carbon pricing increases the bottom decile share by more than 15%. Across most projection years, carbon pricing causes an additional decrease in the Gini coefficient by 3% and, in the top decile share, by more than 4%.

[10] Redistriubuting 6.9% of revenue would be sufficient to get the Gini coefficient back to its BAU level of 0.6825 in 2015. This amount is more than sufficient to return the share of the bottom decile to its BAU. Achieving the latter would require only 1.6% of carbon tax revenue to be devoted to the transfer.

Table 3: Distributional impacts of a global carbon tax with proportional within-country tax incidence

Part I: Between-Country Effect of a Carbon Tax Alone									
	Panel A: World Gini Coefficient			Panel B: World Bottom Decile Share			Panel C: World Top Decile Share		
Year	BAU	Carbon Pring	Change	BAU	Carbon Pricing	Change	BAU	Carbon Pricing	Change
2015	0.6825	0.6846	0.31%	0.0035	0.0034	-1.83%	0.5526	0.5550	0.44%
2035	0.6309	0.6311	0.03%	0.0054	0.0053	-0.15%	0.4955	0.4957	0.04%
2055	0.5876	0.5852	-0.41%	0.0073	0.0075	1.67%	0.4513	0.4490	-0.52%
2085	0.5368	0.5321	-0.88%	0.0102	0.0105	2.94%	0.4036	0.3994	-1.05%
2105	0.5114	0.5065	-0.96%	0.0119	0.0122	2.92%	0.3813	0.3771	-1.10%
Part II: Effect of both Carbon Tax plus Transfers									
	Panel A: World Gini Coefficient			Panel B: World Bottom Decile Share			Panel C: World Top Decile Share		
Year	BAU	Carbon Pring	Change	BAU	Carbon Pricing	Change	BAU	Carbon Pricing	Change
2015	0.6825	0.6540	-4.2%	0.0035	0.0078	120.4%	0.5526	0.5347	-3.2%
2035	0.6309	0.5920	-6.2%	0.0054	0.0112	109.2%	0.4955	0.4712	-4.9%
2055	0.5876	0.5387	-8.3%	0.0073	0.0148	102.1%	0.4513	0.4212	-6.7%
2085	0.5368	0.4946	-7.9%	0.0102	0.0168	64.8%	0.4036	0.3783	-6.3%
2105	0.5114	0.4773	-6.7%	0.0119	0.0173	45.6%	0.3813	0.3611	-5.3%

Note: Income here is measured net of a uniform global carbon tax and an equal per capita global transfer payment (in Part II), but gross of other taxes and transfers.

Figure 3: Global Inequality Reduction with a Carbon Tax and Equal Per Capita Transfer

Panel A: Gini　　Panel B: Bottom Decile Share　　Panel C: Top Decile Share

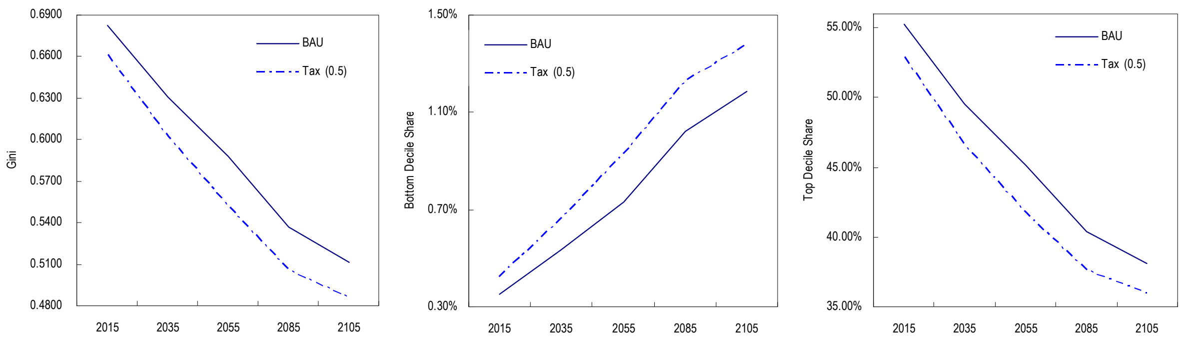
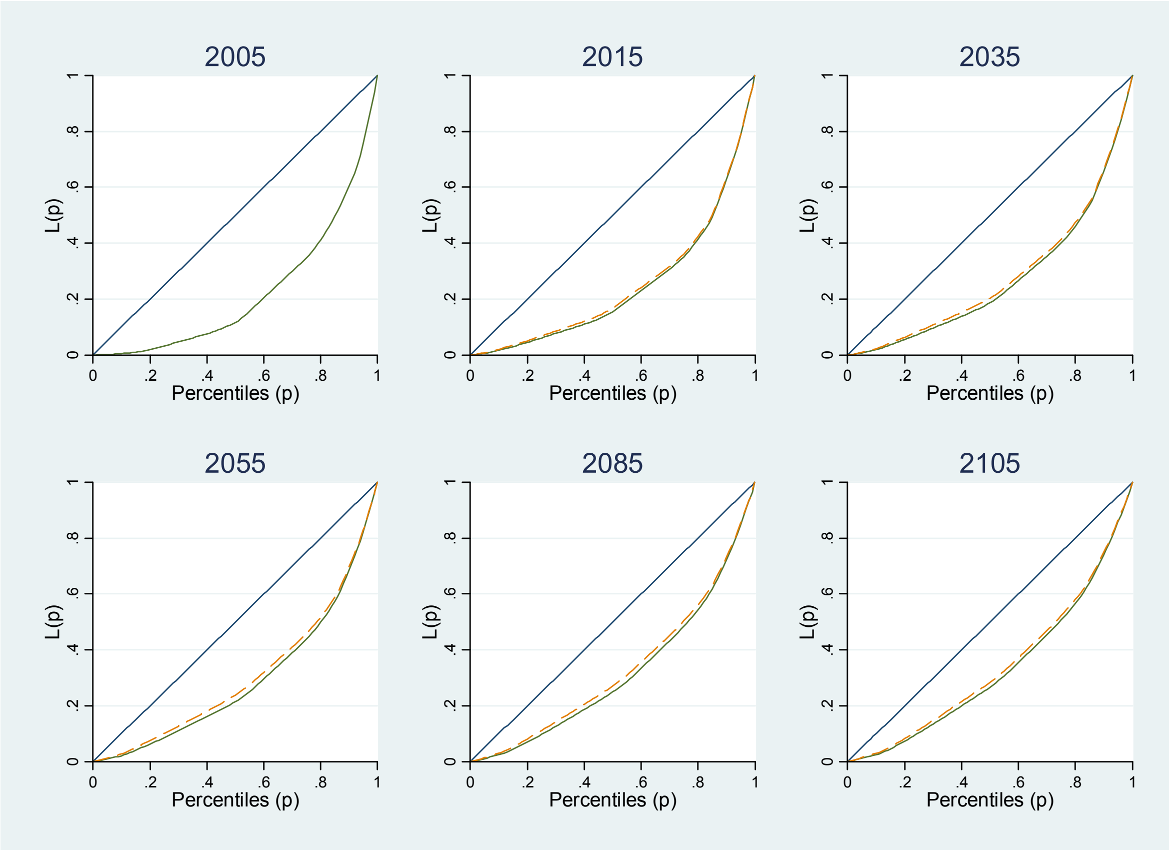


Figure 4 provides a picture of how global inequality evolves through the period under study. This figure plots the Lorenz curves of global income and redistributed incomes after carbon pricing. We see that the body of the Lorenz curve of income shrinks continuously over time, driven mainly by global patterns of economic growth. And in every year, the Lorenz curve of the redistributed income is enveloped by the curve for the before carbon pricing case. This reiterates the impact of carbon pricing in equalizing global incomes further, beyond the impact of country differences in economic growth.

Figure 4: Global Lorenz Curves of Incomes Before and After Redistribution



Note: Lorenz curves of global incomes before and after redistribution are plotted in solid and dashed lines respectively. There is no carbon pricing and redistribution in 2005.

5.2 Poverty Reduction Potential Assuming Proportional Within-Country Incidence of Carbon Tax Incidence

Redistributing revenues from carbon pricing not only equalizes income globally, it also provides promising possibilities to reduce or even remove global absolute poverty. In quantifying the impacts of carbon pricing on global absolute poverty reduction, we consider redistribution of revenues in two ways. The first is to redistribute revenues equally on a per capita basis globally. The second is to use a more pro-poor redistribution scheme in which we redistribute a larger share of revenues to the poor. This second simulation helps us assess whether such a scheme can help erase all poverty by 2015, the time line of the Millennium Development Goals (MGDs).

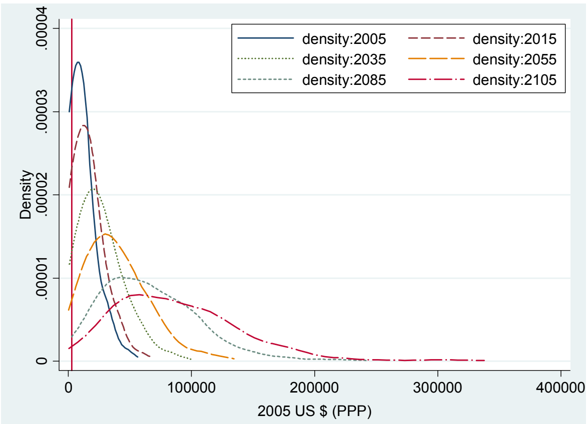
Figure 5 plots the density curves of global income in 2005 US$ PPP terms over time. The vertical line in the figure represents the equivalent poverty line in terms of GDP per capita, at $911 (2005 PPP) equivalent to the current Bank World poverty criterion of $1.25 (2005 PPP) per day. The area under the curve and to the left of the vertical line calculates the portion of people living in poverty. This times the corresponding world population gives a projection of the number of people living in poverty.

Panel A shows that continued global economic growth will be the key force behind poverty reduction in the next 100 years. The global income distribution moves systematically to the right, with poverty decreasing consistently. This process results in a large reduction in global poverty. From Panel A of Figure 5 the poverty rate in 2105 is small relative to 2005. In addition to the secular poverty reduction driven by growth, carbon pricing contributes to this reduction further, as shown in Panel B of Figure 5, where we use the year 2035 as an example.

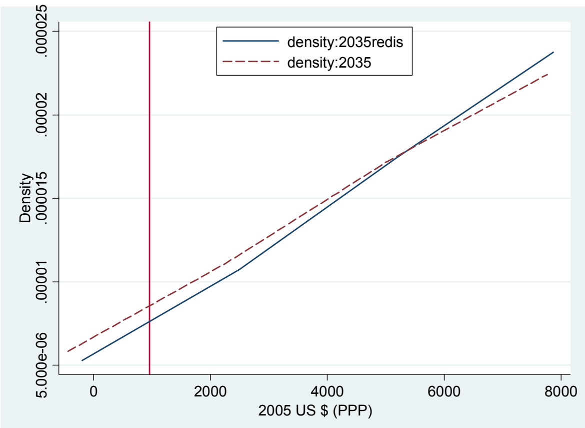
The dashed line is the global density curve around the poverty line in the BAU case, which is higher in the far left tail than the solid line describing the density curve of redistributed global income after carbon taxes. This indicates the area under the solid line and to the left of the poverty line is even smaller, as is the poverty rate. Such a pattern also holds for other projection years which we omit for brevity. This suggests carbon pricing has the potential to reduce poverty further in addition to the growth effect.

Figure 5: Density Curves Of Global Income Distribution

Panel A: Global Income Distribution Across Time



Panel B: Income Distribution Below The Poverty Line Before and After Carbon Pricing (2035)



Note: Panel A plots the density curves of global income across 2005, 2015, 2035, 2055, 2085 and 2105 in the BAU case. Panel B plots the density curves of global income around the poverty line before (labeled by density:2035) and after carbon pricing (labeled by density:2035redis) in 2035, in dash and solid lines respectively. The pattern described by Panel B holds for other projection years.

Using the method given in Section 4, we can also calculate numbers of people living in poverty over time in BAU and carbon-pricing cases. Numbers in both cases and changes in percentage for the BAU case are presented in Table 4. These results suggest that economic growth in the BAU case can reduce poverty substantially over a century, if we adhere to the \$1.25 (2005PPP) per day criterion. There would be around one million people globally living in poverty in 2105 if the global economy continues growing as in the BAU scenario. We thus see a very sharp decrease in the population in poverty across time periods, both in BAU and carbon-tax cases, as plotted in Panel A of Figure 6.

Carbon pricing can also help attain Goal 1 of the Millennium Development Goals (MDGs). In the Millennium Declaration of 2000, 189 nations resolved to "*halve extreme poverty by 2015*", relative to the 1990 level. There are two variants for this target. One is in terms of the share of people in extreme poverty as a percentage of national population, and the other is in terms of the absolute extreme poverty population. Reducing the former is an easier task due to the growth in world population, and several authors even argue we have already attained such a goal (e.g. Bhalla, 2002; Sala-i-Martin, 2002). Our discussions centers on the latter form of target, namely, "*halve extreme poverty population by 2015*".

The estimated population under the international poverty line was 1.82 billion in 1990(See Table 5 of Chen and Ravallion, 2008). Thus, the primary target of Goal 1 of the MDGs translates to around 0.92 billion people living under the international poverty line by 2015 (UN, 2010). Our results in Table 4 indicate that this target can only be met by around 88% $(=\frac{1.82-1.02}{1.82\times 0.5})$ by 2015 if there is no carbon pricing. However, combining economic growth and carbon pricing, we can surpass this target by around 6.6% $(=\frac{1.82-0.85}{1.82\times 0.5}-1)$.

Table 4: Number of Individuals Living In Poverty And Changes, 2015-2105

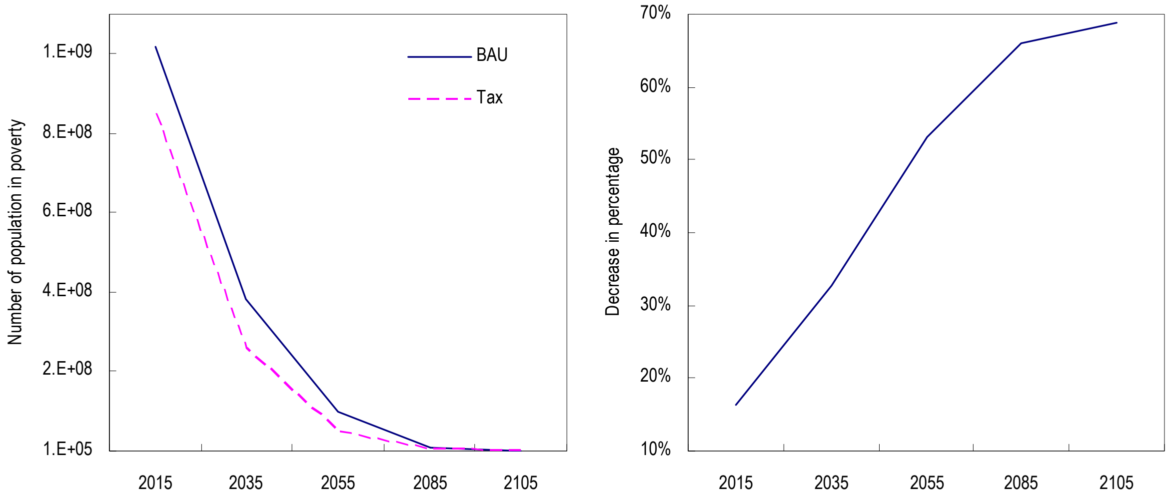
Year	BAU	Tax	Change
2015	1,018,140,019	852,772,758	-16.24%
2035	383,141,322	257,904,611	-32.69%
2055	99,127,246	46,424,115	-53.17%
2085	7,235,425	2,451,849	-66.11%
2105	1,027,082	320,163	-68.83%

Note: These results are estimated by assuming a lognormal distribution for global income. The estimation procedure is given in Section 4.

Going one step further, one may ask whether we could erase global poverty entirely by 2015 if we use the carbon taxes revenues for global poverty reduction. Our results suggest we only need around 33% of the revenues to achieve this goal. Figure 7 plots the population remaining

Figure 6: Population in Poverty and Its Difference Between Cases, 2015 - 2105

Panel A: Numbers in BAU and Carbon Tax Cases Panel B: Difference as Percentage of BAU Case

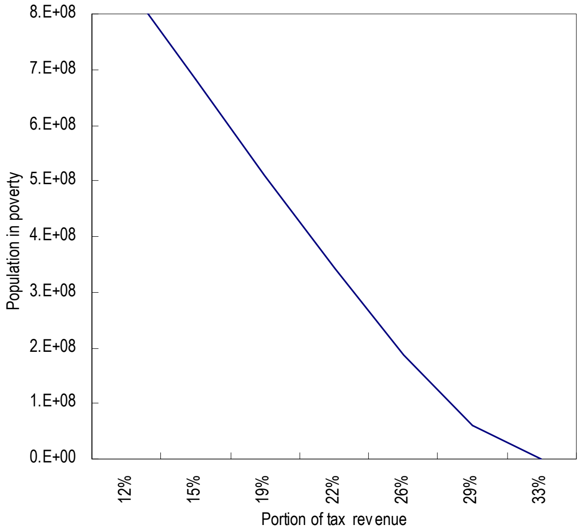


in poverty versus portions of carbon pricing revenues transferred to the poor. In the case where carbon pricing revenues are redistributed on a per capita basis, we transfer around 12% of the carbon pricing revenues to those under the international poverty line. This helps achieve and even surpasses the goal of halving population in poverty by 2015. If we use a mechanism which transfers more carbon pricing revenues to the poor while keeping those just marginally above the poverty line from falling below, we see a steady decrease in the global population in poverty as shown in Figure 7. The world could achieve the more ambitious goal of erasing global poverty by 2015 if such a mechanism were used.

5.3 Global Distributional Impacts of A Global Carbon Tax and Transfer Scheme with Literature-Based Within-Country Incidence of Carbon Tax

This section simulates global distributional impacts of imposing global carbon pricing incorporating within-country incidence effects. Our simulation method assumes lognormal income distribution for each country as in section 4.3 and carbon tax incidence across income levels taken from the literature surveyed in Table 5. Specifically, we begin by creating a sample with 10 people representing deciles within each of the 189 countries included in our experiment. We later use actual country populations as weights in calculating the global Gini coefficient and top and bottom world decile shares. Given the mean and variance for the lognormal wealth distributions (see section 4.3) in each country, we are able to find mean wealth for each decile by integrating under the inverse of the distribution function. This gives the wealth level for the representative individual in each decile. Weighting by the population of each country we

Figure 7: Poverty Population Changes With Portion of Carbon Pricing Revenues Transferred To The Poor By 2015



obtain a global sample of 1890 representative individuals.

Measuring the incidence effects of a carbon tax within countries entails consideration of general equilibrium effects on consumption patterns, production structure and jobs. To quantify within-country incidence effects for the countries included in our analysis one by one is beyond the scope of this paper. Fortunately, there has been much research on carbon tax incidence effects within specific countries. We summarize the results of such studies, where available, for countries in each of the 12 regions specified in section 4.1 (see Table 5), and use them as the basis for our experiments below. [11] An advantage of the studies we have reviewed is that the reported carbon tax burdens include both direct and indirect effects, estimated using either input-output or Computational General Equilibrium (CGE) methods.

For the sake of consistency, we need the average carbon tax rate for each country to be the same as in the calculations of redistributive effects. And this needs to be true for each period. So the tax rates for the different deciles [12] for a country from Table 5 are scaled up to ensure that each country's average tax rate is consistent with those specified in Table 2. Following this, we scale up the within-country incidence effects to the global carbon tax rate specified in

[11] Ideally, we would have the within-country incidence effects data of a carbon tax for every country in our experiments to yield an estimate of global distributional impacts of imposing a global carbon tax. However, we have only such data from a few countries in some of the 12 regions specified in section 4.1, and in this case, we assume the data applies in the entire region.

[12] The missing values for the countries using septimes/sities/quintiles instead of deciles are created by averaging their neighbouring two values. For instance, the missing value for the second decile of UK is replaced by 9.1(=(8.8+9.4)/2) in experiments below.

Table 2 for the years forward in a proportional manner.

Table 5: Estimated carbon tax burdens by country, various studies (% of income)

Panel A : On Deciles

Region	Year	Bottom 1	2	3	4	5	6	7	8	9	Top 10	Tax Rate
US	2003	1.18	1.15	1.24	1.23	1.28	1.21	1.17	1.08	1.03	0.94	$15
EU												
(Netherland)	2000	7	6.1	6	5.3	5.6	5.5	5.2	4.9	4.8	3.9	$30
RUSSIA												
EURO-ASIA												
CHINA	1995	2.1	2	2	1.9	1.9	2.1	2.4	2.8	3.1	3.2	$30
	2007	0.79	0.74	0.73	0.69	0.68	0.68	0.65	0.65	0.64	0.62	$15
INDIA	1998-1999	5.7	5.8	5.9	6.1	6.3	6.9	7.8	8.8	10.1	11.5	$30
OTHER HIGH INCOME												
(Australia)	2007	3.6	2	1.6	1.4	1.1	1.1	0.9	0.8	0.7	0.6	$23

Panel B : On Septimes

Region	Year	Bottom 1	2	3	4	5	6	Top 7	Tax Rate
EU									
(Germany)	1994	8	7.5	7	6.8	6.5	6	5.5	$30

Panel C : On Sixtes

Region	Year	Bottom 1	2	3	4	5	Top 6	Tax Rate
EU								
(UK)	1992	8.8	9.4	10.5	10.4	11.7	7.8	$30
(France)	1992	8.5	7.9	7.3	6.4	5.9	5	$30
(Italy)	1992	11.2	10.9	10.8	10.7	10.6	8.8	$30
(Spain)	1992	8.3	8.1	8	7.9	7.8	7.6	$30

Panel D : On Quintiles

Region	Year	Bottom 1	2	3	4	Top 5	Tax Rate
JAPAN	1995	0.85	0.78	0.76	0.75	0.78	$192
MIDEAST	2005-2009	12.0	10.5	10.3	9.6	8.8	$30
AFRICA	2005-2009	5.8	5.6	5.5	5.6	6.0	$30
LATIN	2005-2009	3.7	3.6	3.8	4.0	3.9	$30
OTHER ASIA	2005-2009	5.5	5.9	6.2	6.5	6.3	$30

Notes:
1. Source: see Appendix.
2. Tax rates here are $ per tonne of carbon. To convert to dollars per tonne of CO_2 requires multiplying the dollars per tonne of carbon by 3.67.

Table 6 summarizes the distributional effects of the global tax and transfer scheme when within-country incidence effects of the tax are modelled. The information provided parallels that shown by Table 3 for the case where the carbon tax was assumed proportional to income within countries and therefore had no within-country incidence effects. Part I of Table 6 indicates that a global carbon tax alone imposes regressive effects on the global income distribution. Global Gini coefficients increase and divides between top and bottom decile shares become larger, not only in 2015 as in Table 3, but in each simulation period through to 2015.

Part II of Table 6 shows that using the carbon tax revenue to fund an equal per capita transfer globally can overcome the regressive impact of the tax alone, and produce an overall equalizing impact throughout 2015-2105. However, the reductions in the Gini coefficient and top decile share, and the increase in the bottom decile share are less than in our earlier analysis ignoring within-country distributional effects of the carbon tax. The results here indicate an average reduction in the Gini coefficient of 2.6% over 2015-2105, an increase in the share of the bottom decile by 81.1%, and a small increase in the share of the top decile, by 1.1%. It is apparent that in order to get a good estimate of the global distributional effects of carbon tax, with or without an accompanying transfer, one needs to model the incidence pattern of carbon taxes within as well as between countries.

Following our discussion of the Table 3 results we asked how much of global carbon tax revenues would need to be devoted to our transfer system in 2015 if the goal were to just offset the disequalizing effect of the carbon tax as indicated by the Gini coefficient. The answer was that only 6.9% of revenue would be sufficient to do that. Once the within-country distributional effects of the tax are brought in, as in Table 6, the answer changes greatly. Now fully 91.3% of revenues must be devoted to the transfer in order to return the Gini coefficient to its BAU level after a carbon tax has been introduced. From 2015 to 2055 this percentage declines to 51.8%, but it then rises to 58.3% in 2105.

Table 6: Distributional impacts of a global carbon tax with literature-based within-country tax incidence

	Part I: Effects of a Global Carbon Tax Alone								
	Panel A: World Gini Coefficient			Panel B: World Bottom Decile Share			Panel C: World Top Decile Share		
Year	BAU	Imposing Carbon Tax	Change	BAU	Imposing Carbon Tax	Change	BAU	Imposing Carbon Tax	Change
2015	0.6825	0.7103	4.1%	0.0035	0.0032	-9.3%	0.5526	0.5787	4.7%
2035	0.6309	0.6574	4.2%	0.0054	0.0049	-7.9%	0.4955	0.5211	5.2%
2055	0.5876	0.6118	4.1%	0.0073	0.0068	-6.9%	0.4513	0.4962	9.9%
2085	0.5368	0.5568	3.7%	0.0102	0.0097	-4.4%	0.4036	0.4285	6.2%
2105	0.5114	0.5286	3.4%	0.0119	0.0114	-4.1%	0.3813	0.4039	5.9%

	Part II: Effects of a Global Carbon Tax plus Transfers								
	Panel A: World Gini Coefficient			Panel B: World Bottom Decile Share			Panel C: World Top Decile Share		
Year	BAU	Imposing Tax plus Transfers	Change	BAU	Imposing Tax plus Transfers	Change	BAU	Imposing Tax plus Transfers	Change
2015	0.6825	0.6786	-0.6%	0.0035	0.0075	113.6%	0.5526	0.5573	0.9%
2035	0.6309	0.6167	-2.3%	0.0054	0.0108	101.4%	0.4955	0.4950	-0.1%
2055	0.5876	0.5631	-4.2%	0.0073	0.0142	93.9%	0.4513	0.4647	3.0%
2085	0.5368	0.5175	-3.6%	0.0102	0.0161	57.5%	0.4036	0.4053	0.4%
2105	0.5114	0.4981	-2.6%	0.0119	0.0165	39.0%	0.3813	0.3864	1.3%

Note: Note: Income here is measured net of a uniform global carbon tax and an equal per capita global transfer payment (in Part II), but gross of other taxes and transfers.

5.4 Redistributing Carbon Pricing Revenues Within Countries Only

One may argue it is more realistic to assume that the revenues from carbon pricing would be redistributed within countries, rather than on a global basis as we have assumed above. [13] Here we contrast the inequality reducing effects of the within-country redistribution approach with those of global redistribution using the Gini coefficient. We consider the case where carbon tax burdens within countries are proportional to income because it allows exact results for the change in the Gini coefficient without any assumption on the shape of the income distributions, and because this case puts the focus more on the role of transfer payments than does the case where within-country incidence effects of carbon tax are allowed. We find that the within-country redistribution scheme reduces global inequality by only a tiny amount, in contrast with our central global redistribution scheme.

Using the decomposition method as in 9, under the assumption that carbon taxes are proportional to income within countries, the change in the global Gini coefficient under the within-country redistribution scheme comes only from the first term in the equation, which reflects within-country inequality. The second term, which measures between-country inequality, and the third residual term are unaltered because revenues are retained and fully reallocated within each country. We use equation 10 to measure the within-country changes of Gini coefficients due to imposing a uniform global carbon tax with lump-sum redistribution of retained revenues domestically on an equal per capita basis. Table 7 presents the global Gini coefficient changes over time under the within country redistribution scheme.

Table 7: Global Inequality Reduction With Global Carbon Tax Revenues Retained and Redistributed Within Countries

Year	Gini(BAU)	Gini(Within-Scheme)	Change
2015	0.6825	0.6822	-0.04%
2035	0.6309	0.6306	-0.05%
2055	0.5876	0.5873	-0.06%
2085	0.5368	0.5365	-0.06%
2105	0.5114	0.5112	-0.05%

Comparing the changes of global Gini coefficients in Table 7 with those in Table 3 indicates that the within scheme generates a very small global equalizing effect. This is largely because, globally, between-country inequality dominates within-country inequality. In the BAU scenario, the between-country term in equation 10 accounts for about 70% of the global Gini coefficients

[13] We thank one of the anonymous referees for emphasizing this point.

on average over time. Hence a carbon pricing scheme redistributing revenues only within countries has a minor equalizing effect on global income distribution. Bringing literature-based within-country carbon tax burdens into the picture would produce a net disequalizing effect. Thus consideration of the within scheme provides further grounds for a global carbon pricing scheme to be accompanied by worldwide redistribution.

6 Concluding Remarks

In this paper, we have quantified the potential impacts of full global carbon pricing on global inequality and the implications for global poverty reduction. We have used the projections from Nordhaus's (2010) RICE model to set up a business as usual (BAU) scenario and a counterfactual under which global temperature increase is limited to 2°C over a 100 year time frame. We have assumed a time-stable price elasticity of demand for fossil fuels and different energy efficiency improvement factors across countries in counterfactual scenarios. Fully global carbon pricing yields revenues of 6% of world gross product on average over our projection years.

We have simulated the between- and within-country impacts of a uniform global carbon tax. The between-country effect is initially regressive since the highest income countries have below-average emissions. However, reductions in climate damage in less temperate regions and energy efficiency improvements in low and middle income countries soon reverse this picture and after about 2035 the between-country impacts of the carbon tax become increasingly progressive. Using literature-based estimates, we find that the within-country incidence of the carbon tax is, however, always regressive and dominates the progressive between-country impact of later years. The global distributional effects of imposing a uniform global carbon pricing are thus found to be regressive.

Offsetting the regressivity of a global carbon tax, using the revenues to provide an equal per capita global transfer, generates major incremental global poverty reductions in addition to those produced by economic growth. Considering all aspects of the tax and transfer scheme, we obtain an average decrease in the global Gini coefficient of 2.6% relative to the BAU over 2015-2105, an increase in the share of the bottom decile of 81.1% and a small increase in the share of the top decile by 1.1%. The global number of poor is reduced 16% in 2015 under this scheme. However, using a more pro-poor redistribution scheme which allocates a larger share of revenues to the extreme poor, we find that poverty can be erased by the MDG deadline year of 2015 at a cost of only 33% of carbon pricing revenues.

There may of course be strong political impediments to redistributing all the revenue from a global carbon tax evenly around the world. We have looked at the impact of redistributing revenues solely within country borders, and find that it is tiny. The global carbon tax has strong appeal, especially from an efficiency viewpoint, but has a distributional handicap. Redistributing a substantial part of revenues globally is necessary to neutralize the global impact on inequality and poverty, and we think is likely necessary to create an international consensus in support of the tax. We find that if redistribution is to occur via an equal global per capita transfer, then in 2015 it would be necessary to redistribute 91% of the revenues to offset the rise in the Gini coefficient caused by the tax. In later years, this requirement is softened, with the amount needed for redistribution falling to 50-60% of revenues.

Our results suggest that uniform global carbon pricing presents both a challenge and an opportunity in the context of global inequality and poverty. The challenge is that, without effective redistribution, global carbon pricing will increase global inequality and poverty. The opportunity is presented by the large revenues that would be created. If redistributed globally, these revenues are sufficient to reduce global inequality and poverty significantly, as we have shown. And if even just one third of the revenues were redistributed in a targeted fashion they could eliminate world poverty by 2015, going far beyond the MDG goal of cutting world poverty in half by that year.

Our results also sound a cautionary note. If redistribution is pursued only within countries, the overall results of a global carbon tax are likely to be an increase in inequality and poverty globally. The disequalizing nature of the carbon tax on its own means that we must be careful how the revenues are used. We have seen that an overall disequalizing effect could be avoided even without devoting all carbon tax revenues to redistribution, but care must be taken not to overdo the diversion of funds to other purposes. According to our estimates a global carbon tax could generate revenues much larger than, for example, the $30 billion in new commitments to adaptation funds in the Copenhagen Accord of 2009. Global carbon tax revenues would provide an opportunity to address thorny problems in climate financing program such as providing the funds requested by the developing countries for their GHG emission reduction so as to give them incentives to be actively engaged in global emissions reduction. But too much use of revenues for these and other similarly laudable purposes could limit the potential equalizing effect from redistributing carbon tax revenues and therefore sap needed international support for global carbon pricing.

Finally, our finding that global redistribution of carbon tax revenues is needed to avoid an overall regressive impact of a global carbon tax suggests the necessity of setting up a global mechanism to coordinate the implementation of a global carbon tax and collect and manage the revenues from such a tax. We would argue that setting up an international agency, perhaps under the framework of the G20, to do this is a promising policy option to consider. Such an initiative may be unavoidable if we wish to make a global carbon tax a practical proposal, rather than merely a theoretical possibility.

References

[1] Avi-Yonah, R.S., David M. Uhlmann. Combating Global Climate Change: Why a Carbon Tax Is a Better Response to Global Warming Than Cap and Trade. Stanford Environmental Law Journal, 2009, 28(3):1-50.

[2] Bhalla, S.S., 2002. Imagine There is No Country: poverty, inequality, and growth in the era of globalization, Institute for International Economics, Washington, DC.

[3] Bagnoli, P., J. Château and Y. G. Kim, 2008. The Incidence of Carbon Pricing: Norway, Russia and the Middle East. OECD Economic Studies, 44(1):1-26.

[4] Boyce, J.K., Riddle, M.E., 2009. Cap and Dividend: a State-by-State Analysis. Working Paper, Political Economy Research Institute, University of Massachusetts, Amherst.

[5] Brennera, M., M. Riddleb, and J.K. Boycec (2007). A Chinese Sky Trust? Distributional Impacts of Carbon Charges and Revenue Recycling in China. Energy Policy, 35(3):1771-1784.

[6] Cao, J. (2010). The Incidence of Carbon Tax in China. Lincoln Institute China Program Annual May Conference, Cambridge, USA.

[7] Cowell, F.A., 1977. Measuring Inequality. Oxford: Phillip Allan Publishers.

[8] Chen, S., Ravallion, M., 2008. The Developing World Is Poorer Than We Thought, But No Less Successful In Fighting Against Poverty. World Bank Policy Research Working Paper No. 4703.

[9] Datta, A. 2010. The Incidence of Fuel Taxation in India. Energy Economics, 32, Supplement 1:S26CS33.

[10] Davies, J.B. and A.F. Shorrocks, 1989. Optimal Grouping of Income and Wealth Data, Journal of Econometrics, 42: 97-108.

[11] Deaton, A., 2008. How to Monitor Poverty for the Millennium Development Goals. *Journal of Human Development* 4: 353 - 378.

[12] EIA, 2010. http://www.eia.doe.gov/pub/oil_gas/petroleum/analysis_publications/primer_on_gasoline_prices/html /petbro.html.

[13] Granado,J.A., D. Coady, and R. Gillingham, 2010. The Unequal Benefits of Fuel Subsidies: A Review of Evidence for Developing Countries. International Monetary Fund Working Paper, WP/10/202.

[14] Grubb, M. and S. Droege, 2010. A Carbon Giveaway Europe Cannot Afford. *Financial Times*, June 14. http://www.ft.com/cms/s/0/cfdb84f2-77e8-11df-82c3-00144feabdc0.html.

[15] Hassett, K.A., A. Mathur and G.E. Metcalf (2007). The incidence of a U.S. carbon tax: A lifetime and regional analysis. NBER Working Paper 13554

[16] IEA, 2008. Worldwide Trends in Energy Use and Efficiency : Key Insights from IEA Indicator Analysis. Paris: International Energy Agency.

[17] IPCC (Intergovernmental Panel on Climate Change), 2000. Special Report on Emissions Scenarios. Cambridge: Cambridge University Press.

[18] IPCC (Intergovernmental Panel on Climate Change), 2007. Climate Change 2007: Synthesis Report. IPCC Plenary XXVII, Valencia.

[19] IIASA (International Institute of Applied Systems Analysis) World Population

[20] Kakwani, N.C., 1976. Measurement of Tax Progressivity: An International Comparison. *The Economic Journal* 87: 71-80.

[21] Kemp-Benedict, E., 2001. Income Distribution and Poverty: Methods for Using Available Data in Global Analysis. PoleStar Technical Notes No.4.

[22] Komanoff, C., 2010. Carbon Tax Center (CTC) CARBON TAX_ 4_Sector Model, www.carbontax.org.

[23] Kerkhof, A. C., H. C. Moll, E. Drissen and H. C. Wilting, 2008. Taxation of Multiple Greenhouse Gases and the Effects on Income Distribution: A Case Study of the Netherlands. Ecological Economics, 67:318-26.

[24] Lipow, G.W., 2010. Energy Price Demand Elasticity. www.carbontax.org.

[25] Milanovic, B., 2005. Worlds Apart: Measuring International and Global Inequality. New Jersey: Princeton University Press.

[26] Milanovic, B., 2009. Global inequality recalculated: The effect of new 2005 PPP estimates on global inequality. MPRA Paper No. 16538.

[27] Nordhaus, W., 2008, A Question of Balance: Weighing the Options on Global Warming Policies. New Haven & London: Yale University Press.

[28] Nordhaus, W., 2010, Papers and Files for RICE-2010 Model (May 2010), http://nordhaus.econ.yale.edu/.

[29] Nordhaus, W.D., 2007. To Tax or Not to Tax: Alternative Approaches to Slowing Global Warming. Review of Environmental Economics and Policy, 1(1):26-44.

[30] Okushima,S. 2003. Global Warming Policy and Distributional Effects: A General Equilibrium Analysis. Paper presented in CEF 2003.

[31] Orlov, A., H. Grethe and S. McDonald, 2010. Energy Policy and Carbon Emission in Russia: A Short Run CGE Analysis. University of Hohenheim, Department of Agriculture and Food Policy, Working paper, WP2010-4.

[32] Sala-i-Martin, X., 2002. The disturbing "rise" of global income inequality, NBER Working Paper No. 8904, NBER, Cambridge, MA.

[33] Shorrocks, A., and D. Mookherjee, 1982. A Decomposition Analysis of the Trend in UK Income Inequality. *The Economic Journal* 92: 886-902.

[34] Stern, N., 2007. The Economics of Climate Change: The Stern Review. Cambridge: Cambridge University Press.

[35] Shah, A. and B. Larsen (1992): Carbon Taxes, the Greenhouse Effect, and Developing Countries. Policy Research Working Paper Series 957, The World Bank.

[36] Siriwardana, M., S. Meng and J. McNeill, 2011. The Impact of a Carbon Tax on the Australian Economy: Results from a CGE Model. University of New England, School of Business, Economics and Public Policy, Working Paper, No.2011 C 2.

[37] Symons, E.J., S.Speck and J.L.R.Proops (2000). The Effects of Pollution and Energy Taxes across the European Income Distribution. Working Paper, Economics Department, Keele University, UK.

[38] UN (United Nations) United Nations. Department of Economic and Social Affairs, Population Division. 2004. World Population to 2300. ST/ESA/SER.A/236. New York: United Nations.

[39] UN (United Nations), 2010. Millennium Development Goals. http://www.un.org/millenniumgoals/.

[40] UN (United Nations), 2007. Expert Group on Energy Efficiency, 2007: Realizing the Potential of Energy Efficiency: Targets,

[41] Yusuf, A.A., B. Resosudarmo. On the Distributional Effect of Carbon Tax in Developing Countries: The Case of Indonesia. Working Paper, Padjadjaran University. Forecast Period 2000-2100, 2001 Revision. Available online at http:// Policies, and Measures for G8 Countries. Washington: United Nations Foundation. Program. 2007. Probabilistic Projections by 13 World Regions, www.iiasa.ac.at/Research/POP/proj01/.

Appendix

This appendix gives the sources of the estimates of carbon tax incidence for various countries shown in Table 5 of the paper. The US figures follow Hassett, Mathur and Metcalf (2007).

Data for EU countries (Germany, UK, France, Italy, Spain) are from a survey paper of Symons, Speck and Proops (2000). Kerkhof, Moll, Drissen and Wilting (2008) present the Netherlands data. Okushima (2003) projects the data for Japan (JPN) in 2010. Datta (2010, table 2) uses a composite tax for petrol diesel LPG kerosene for India (IND). The data for China use results from Cao (2010). Granado, Coady and Gillingham (2010) presents distributional impacts across Africa, South and Central America (corresponding to "Latin" in our table), Asia Pacific (corresponding to "Other Asia" in our table), and the Middle East. The data for Australia (representing OTHER HIGH INCOME countries) are from Siriwardana, Meng and McNeill (2011). Estimates for Russia and countries in Euro-Asia are not yet available in the literature, as far as we know. The few sources on Russia such as Bagnoli, Château and Kim (2008) and Orlov, Grethe and McDonald (2010) do not present results on the impacts of carbon tax on income deciles. In our experiments, we use the Mideast incidence data for Russia as well, in view of the similarly large hydro-carbon deposits in the two areas (Bagnoli, Château and Kim, 2008). We use the world average for Euro-Asia.