Equity Implications of the COP21 Intended Nationally Determined Contributions to Reduce Greenhouse Gas Emissions

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Abstract

The recent Conference of the Parties to the UN Framework Convention on Climate Change (COP21) resulted in voluntary greenhouse gas (GHG) reduction commitments by 195 countries. The purpose of this paper is to analyze the equity implications of this "bottom-up" approach to climate change negotiations in two major ways. First we analyze the GHG reduction targets specified in the COP 21 agreement prior to any emissions trading in terms of the equity metrics of the Gini Coefficient and Atkinson Index. We also match the commitments with specific equity principles, such as the Egalitarian, Ability to Pay, Vertical, and Horizontal equity. Second, we analyze the equity and economic welfare outcomes after emissions trading takes place. We adapt a non-linear programming model well suited to this purpose, which determines the equilibrium emission allowance price, mitigation costs, and allowance purchases and sales between countries from trading. We also test the sensitivity of the results to macroeconomic conditions and technological change. Our findings are that the GHG reduction commitments made at COP 21 run counter to most equity principles. They are definitely a major departure from the Egalitarian, Vertical, and Rawlsian equity principles proposed for many years by developing countries.

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I. Introduction

Negotiations on a global agreement to address climate change are now well into their third decade. One key consideration has been the distribution of the burden of mitigating and sequestering greenhouse gases (GHGs). Until recently, the approach has been "top-down," with nations trying to agree on a broad principle of equity, or fairness, by which to assign initial emission reduction targets to each participant, and which subsequently determine the distribution of tradable emission allowances. Progress was slow for many reasons, including the myriad of alternative equity and differentiation principles that were put forth. Major emitters, such as China, India, and the United States, never formally committed to binding emission caps under the Kyoto Protocol, the first major accord on targets and timetables for GHG reduction, nor to its successor agreements.

A few years ago, momentum began building on a "bottom-up" approach, by which each nation sets its own emission reduction target and timetable. This has relieved many of the tensions and obstacles in formulating an international agreement. It has allowed for voluntary commitments on the part of major emitters of GHGs who did not ratify the Kyoto Protocol. The Conference of the Parties to the UN Framework Convention on Climate Change (COP21), recently held in Paris, resulted in voluntary GHG reduction commitments by 195 countries. One major question that arises, however, is: What are the equity implications of the initial GHG reduction allocations and welfare outcomes of this agreement?

The purpose of this paper is to analyze the equity implications of the bottom-up approach to climate change negotiations in two major ways. First we will analyze the GHG reduction targets specified in the recent COP 21 agreement prior to any emissions trading in terms of the equity metrics of the Gini Coefficient and Atkinson Index. We will also match the results with specific equity principles, such as the egalitarian, ability to pay, vertical equity, horizontal equity, and Rawlsian Maximin principles (Kverndokk and Rose, 2008; IPCC 2014).

Second, we will analyze the equity and economic welfare outcomes after emission trading takes place. We adapt a non-linear programming model well suited to this purpose, which determines the equilibrium emission allowance price, equilibrium mitigation costs, amount of allowance purchases and

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sales between countries, and the individual country and overall gains from allowance trading (Rose et al., 1998; Rose and Wei, 2008). An innovative aspect of this analysis includes: consideration of macroeconomic effects, the potential role of emission offsets, and sensitivity tests on alternative stationary and mobile source technologies.

Our initial analysis focuses on 3 regions/countries: China, the European Union, and California. We will then discuss the implications of bringing additional countries into the agreement, a formal analysis of which will be completed by the time of the EAERE Conference. Our initial choice of countries/regions is related to recent developments of non-standard approaches to climate change negotiations. For example, California itself is the 6th largest economy in the world, and its current and former governors have been in the forefront of climate change policy initiatives. On one of his last official activities, UK Prime Minister Tony Blair visited California to discuss the prospects of emissions trading between the state and the EU.[2] Also, even more recently China and the U.S. have committed to a bilateral agreement to reduce GHGs. The analytical framework is, of course, generalizable to the 195 counties that are parties to the COP 21 Accord.

Our findings are that the GHG reduction commitments made at COP 21 run counter to most equity principles. They are definitely a major departure from the Egalitarian, Vertical, and Rawlsian equity principles proposed for many years by developing countries.

The analysis should prove useful to policy makers negotiating climate policy agreements and designing cap and trade systems. It will yield insights into promoting more equitable outcomes in terms of both the distribution of the mitigation burden and with respect to broader strategies for assigning responsibilities for GHG emissions, including commitments from a broader set of countries and targeting specific technological improvements.

II. Pre-Trading Equity Analysis

A. Basic Data

At COP21, 195 counties and one regional government agreed to Intended Nationally Determined Contributions (INDCs) to reduce GHG emissions (UNFCCC, 2015). Table 1 presents the GHG emission reduction commitments for the year 2030 for nearly 100 countries that made *unconditional* commitments that could be quantified in terms of percentage emission reductions at COP21 (Carbon Brief, 2015). The countries are listed in descending order of their absolute reduction commitment, which for several counties needed to be translated from other base years (e.g., 15% below Year 2005 levels) and adjusted to Year 2030 mission projections. Also, some countries, mainly developing ones, made *conditional* commitments contingent on financial assistance from

[2] Given the slow progress in passing federal climate mitigation legislation in the US, emissions trading via individual states may in fact be the process by which the COP21 commitments are actually implemented in the near term.

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Table 1. Unconditional GHG Mitigation Pledges, 2030

Unconditional GHG Mitigation Pledges						
Country	GDP (billions of 2010US$)	Population (millions)	Per Capita GDP (thousands 2010US$)	Projected BAU Emissions (MtCO2e)	Absolute Emission Reduction (MtCO2e)	Percentage Emission Reduction (%)
USA	23,857.4	355.8	67.0	7,586.0	3,122.0	41.2
China	18,829.4	1,413.9	13.3	20,036.0	2,061.9	10.3
EU	22,908.4	513.8	44.6	4,977.0	1,835.8	36.9
Brazil	3,161.2	228.7	13.8	2,061.0	864.0	41.9
Indonesia	2,077.2	295.5	7.0	2,881.0	835.5	29.0
Russia	2,218.9	134.0	16.6	2,437.0	423.8	17.4
Japan	6,535.3	120.2	54.4	1,352.0	310.1	22.9
Mexico	1,970.4	148.1	13.3	1,110.0	277.5	25.0
Ethiopia	137.6	138.3	1.0	400.0	256.0	64.0
Australia	1,943.1	27.9	69.6	621.0	213.1	34.3
Kazakhstan	339.7	19.4	17.5	461.0	211.5	45.9
Saudi Arabia	1,204.9	39.1	30.8	844.0	130.0	15.4
Thailand	608.9	68.3	8.9	555.0	111.0	20.0
Argentina	610.7	49.4	12.4	670.0	100.5	15.0
Gabon	34.6	2.3	14.9	192.5	96.3	50.0
Colombia	683.1	53.2	12.8	335.0	67.0	20.0
Viet Nam	378.5	99.3	3.8	787.4	63.0	8.0
Tunisia	92.1	12.3	7.5	68.2	62.2	8.8
Belarus	66.0	8.6	7.7	95.0	56.0	59.0
Paraguay	40.2	7.8	5.1	416.0	41.6	10.0
Peru	356.9	36.9	9.7	139.3	27.9	20.0
Israel	476.9	10.1	47.1	105.5	24.7	23.4
Zambia	68.3	25.3	2.7	96.0	24.0	25.0
Morocco	184.6	39.8	4.6	171.0	22.2	13.0
Algeria	304.6	48.3	6.3	309.0	21.6	7.0
Togo	7.3	10.5	0.7	38.9	20.7	53.3
Iran	857.1	88.5	9.7	465.9	18.6	4.0
Trinidad and Tobago	29.7	1.4	21.6	62.0	18.6	30.0
Ecuador	142.2	19.6	7.3	75.0	17.0	22.7
Botswana	30.5	2.8	10.8	23.0	15.9	69.3
Tanzania	118.9	82.9	1.4	153.0	15.3	10.0
Bangladesh	381.2	186.5	2.0	234.0	11.7	5.0
Ghana	94.4	36.9	2.6	74.0	11.1	15.0
Ivory coast	59.8	32.1	1.9	34.3	9.6	28.0
Burkina Faso	24.4	27.2	0.9	118.3	7.8	6.6
Lebanon	61.3	4.6	13.2	44.0	6.6	15.0
Guatemala	84.9	21.4	4.0	53.9	6.0	11.2
Georgia	21.3	4.1	5.2	38.4	5.8	15.0
Chad	21.7	21.9	1.0	28.7	5.2	18.2

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Sri Lanka	165.9	22.2	7.5	56.0	3.9	7.0
Serbia	66.8	6.4	10.5	66.0	3.6	5.5
Niger	16.8	36.0	0.5	96.5	3.4	3.5
Eritrea	4.2	7.3	0.6	6.3	2.5	39.2
Namibia	23.9	3.3	7.3	22.7	2.0	8.9
Senegal	28.5	22.8	1.3	40.0	2.0	5.0
Oman	103.6	5.2	19.8	90.5	1.8	2.0
Djibouti	2.8	1.1	2.6	4.5	1.8	40.0
Gambia	2.0	3.1	0.7	3.9	1.8	45.0
Haiti	13.0	12.6	1.0	20.5	1.0	5.0
Bosnia and Herzegovina	29.7	3.6	8.3	40.9	0.82	2.0
Benin	14.3	15.6	0.9	22.5	0.79	3.5
Jordan	47.8	8.0	6.0	51.0	0.77	1.5
Kyrgyzstan	9.5	7.1	1.3	4.5	0.57	12.6
Mauritania	13.4	5.7	2.4	18.8	0.50	2.7
Yemen	44.7	36.3	1.2	43.8	0.44	1.0
Fiji	5.2	0.9	5.5	3.5	0.35	10.0
Maldives	6.3	0.5	12.8	3.3	0.33	10.0
Lesotho	5.7	2.5	2.3	2.9	0.29	10.0
Andorra	7.7	0.1	108.6	0.5	0.20	37.0
Seychelles	2.5	0.1	25.7	0.7	0.19	29.0
Nigeria	916.4	262.6	3.5	0.9	0.18	20.0
Saint Vincent and the Grenadines	1.0	0.1	9.3	0.7	0.15	22.0
Micronesia	0.3	0.1	2.7	0.2	0.13	55.0
Dominica	0.6	0.1	8.2	0.2	0.13	58.9
Liechtenstein	11.6	0.0	282.3	0.3	0.11	45.1
Marshall Islands	0.3	0.1	4.6	0.2	0.10	53.8
Angola	210.0	39.4	5.3	0.2	0.08	35.0
Azerbaijan	91.9	10.4	8.8	0.1	0.03	35.0
Solomon Islands	1.4	0.8	1.8	0.1	0.02	30.0
Kiribati	0.2	0.1	1.6	0.1	0.02	12.8
Cook Islands	NA	NA	NA	0.1	0.01	6.4
Burundi	5.7	17.4	0.3	0.1	0.002	3.0
Jamaica	20.9	2.9	7.2	0.0	0.001	7.8
Tajikistan	12.6	11.1	1.1	21.7	-3.3	-15.1
Moldova	12.1	3.2	3.8	11.0	-4.0	-36.1
Sierra Leone	6.8	8.6	0.8	6.6	-5.2	-79.9
Singapore	464.9	6.4	72.8	33.0	-38.5	-116.8
Chile	495.0	20.3	24.4	151.0	-70.6	-46.7
Uruguay	80.0	3.6	22.3	43.0	-73.2	-170.1
Ukraine	203.3	40.3	5.0	461.0	-105.6	-22.9
Malaysia	602.7	36.1	16.7	479.0	-310.6	-64.8
India	6,310.0	1,527.7	4.1	5,833.0	-3,615.6	-62.0
All Countries Totals	101,085.6	6,628.4	15.3	57,790.7	7,153.3	12.4
Countries with Positive Reductions Totals	92,898.2	4,971.1	18.7	50,751.5	11,379.9	22.4

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industrialized countries. Several countries included prospective emission allowance purchases toward their commitments, so we excluded them as well. Also, because some contributions could not be translated into precise commitments, we could not include all countries in the analysis. However, our sample includes countries with 81.5 percent of total projected GHG emissions in 2030, so we believe it is representative of the total set of parties to the agreement.

B. Index Analysis

1. Gini Coefficients

The Lorenz Curve and Gini Coefficient are the most commonly used approach to describe and measure the level of inequality. They are typically applied to income distribution, by examining the relations between income shares and population shares (the Lorenz Curve is essentially a cumulative frequency distribution, and the Gini is a one-parameter measure of inequality derived from it in relation to a line of perfect equality).[3] In this study, we adapt this approach to examine the equity implications of the distribution of emission reduction targets among countries. We utilize the data in Table 1 in various formats. The Lorenz Curve and Gini Coefficient are straightforward when applied to measuring ordinary income inequality: individuals or income brackets (typically involving the same number of individuals in each bracket) are ordered in ascending order of income on the horizontal axis and the cumulative share of income is measured on the vertical axis. However, the case in point in our paper is open to several interpretations. Below, we first perform the analysis of inequality in terms of country differentials in population and per capita GDP along the horizontal axis. Then we perform an analysis giving each country equal weight on the horizontal axis, though the countries are ordered according to per capita emission reduction commitments and according to per capita GDP emission reduction commitments (the cumulative frequency of which appear on the vertical axis) in ascending order. Note that both approaches have been used to construct Lorenz curves for carbon inequality analysis (Clarke-Sather et al., 2011; Teng et al., 2011), though only Groot (2010) has applied them to analyzing the distributional implications of GHG mitigation.

Figure 1 presents a Lorenz Curve that corresponds to Table 1. The horizontal axis indicates the cumulative shares of population and the vertical axis indicates the cumulative shares of the 2030 unconditional emission reductions. In order to construct the Lorenz curve, we first sort the 73 countries with positive unconditional emission reduction targets by per capita emission reduction in ascending order. The 45 degree line (the Equality line) represents the condition of equal per capita emission reduction across countries. Therefore, the Lorenz curve indicates the inequality of commitments in relation to population. For example, China is on the bottom end of the Lorenz curve, where the slope of the curve is lower than the slope of the Equality line. That means China committed to a smaller share of emission reduction (17.4%) in relation to its population share (28.4%). EU and US are both on the top end of the Lorenz curve, where the slope of the curve is higher than the slope of the Equality line. Both region/country commit a larger share of emission reduction (16.1% and 27.4%, respectively) with respect to their population share (10.3% and 7.2%, respectively). The Gini coefficient is computed in

[3] We acknowledge the limitations of a one-parameter measure (see, Atkinson, 1970; Braun, 1988).

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the typical way by dividing the area between the Lorenz curve and the Equality line by the entire triangle area below the Equality line. The Gini coefficient corresponding to the Lorenz curve in Figure 1 is 0.498. This represents a considerable departure from the perfect equality case as indicated by the Equality line depicted in Figure 1.

In Figure 2, we constructed a similar Lorenz curve to examine the relations between emission reduction shares and per capita GDP shares. In this case, the Lorenz curve indicates the inequality of commitments in relation to per capita GDP. It thus reflects the relationship between GHG reduction commitments and the level of economic development. For example, Liechtenstein, Australia, and Japan are on the bottom end of the Lorenz curve, meaning they are committed to less emission reduction in relation to their per capita GDP level. EU, US, and China are on the upper end of the Lorenz curve, meaning these three countries are committed to more emission reduction in relation to their per capita GDP level. The Gini Coefficient here is 0.825, which reflects a very high level of inequality. Figure 3 presents a Lorenz Curve for which the horizontal axis indicates the countries (each given equal weight) and the vertical axis indicates the cumulative shares of the 2030 unconditional emission reductions per capita. Note that the vertical axis differs from the counterpart Figure 1, though the two figures convey the same concept of inequality of commitments in relation to population; the difference in the axes is necessary in the case of Figure 3 in order to capture the population variable because the horizontal axis in this case is not able to do so. The important comparison is in the Gini Coefficients between the two figures. For Figure 3 it is 0.718, as compared to 0.498 in Figure 1. In general, the two figures confirm that commitments in relation to populations are skewed. We will examine the implications further in the discussion of correlations below.

Figure 4 also uses the equal weighting system along the horizontal axis, but is intended to measure inequality of emission reduction commitments in relation to per capita GDP. Hence, it is the counterpart of Figure 2. As in Figure 3, however, we must modify the vertical axis by expressing it in terms of per capita GDP, because, once again, the equal weighting of countries on the horizontal axis cannot convey other variables. For this case the Gini Coefficient is 0.835, which is almost exactly the same as the Gini Coefficients of 0.825 in Figure 2.

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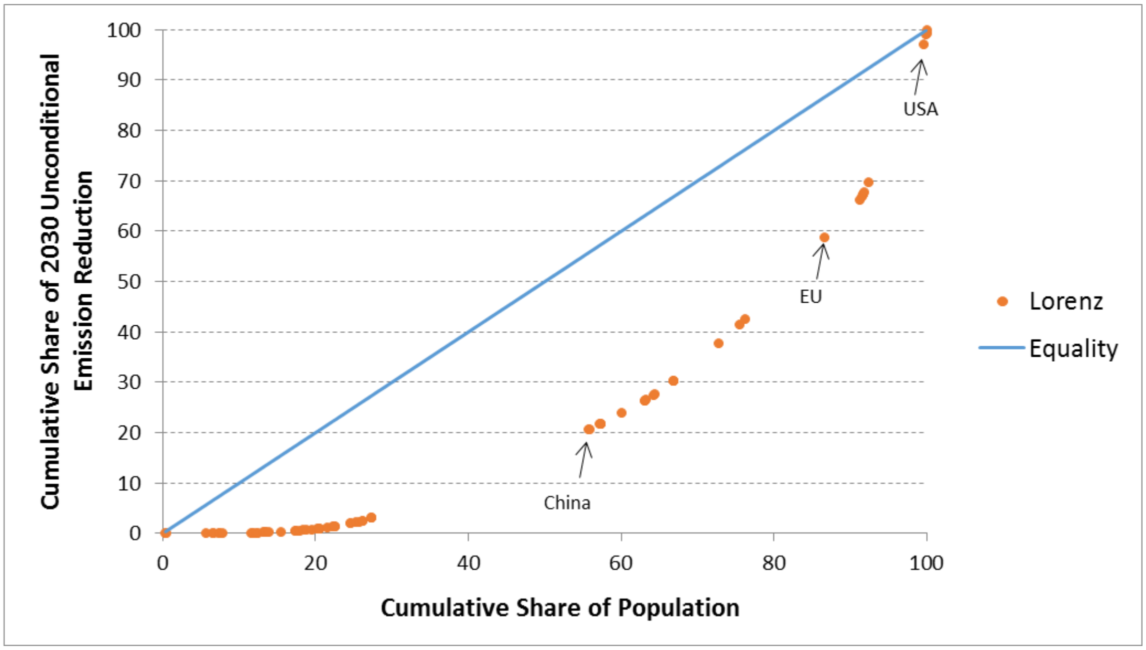

Figure 1. **Lorenz Curve in Relation to Population**
(countries are ordered by per capita emission reduction commitments)

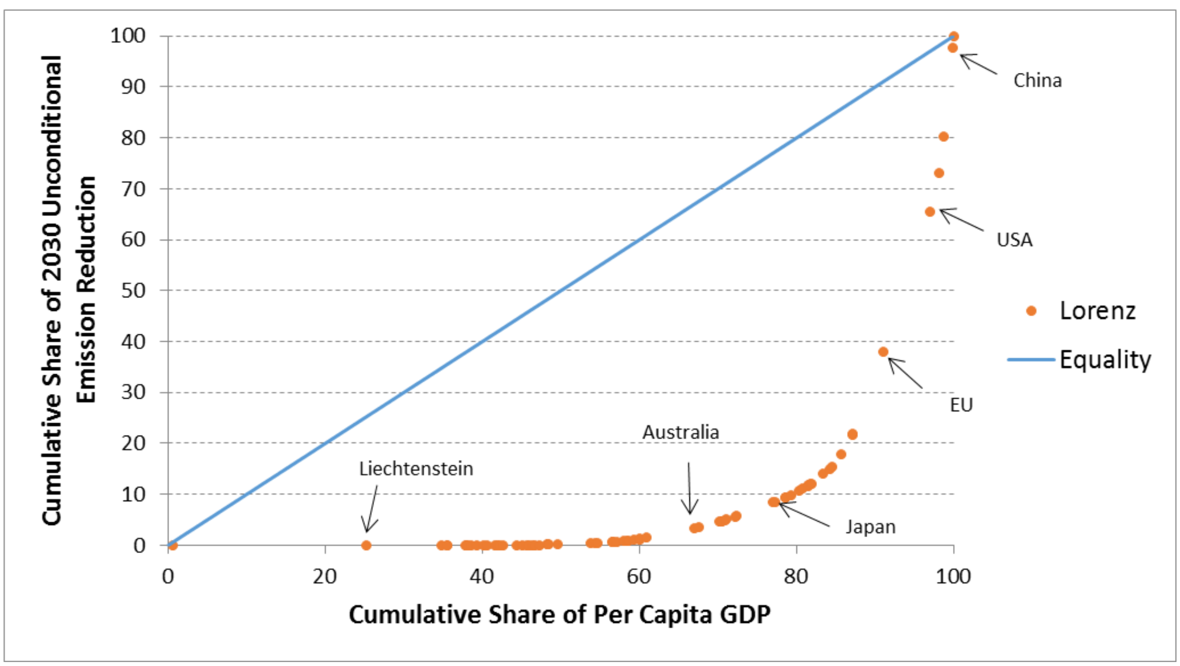

Figure 2. **Lorenz Curve in Relation to Per Capita GDP**
(countries are ordered by per capita GDP emission reduction commitments)

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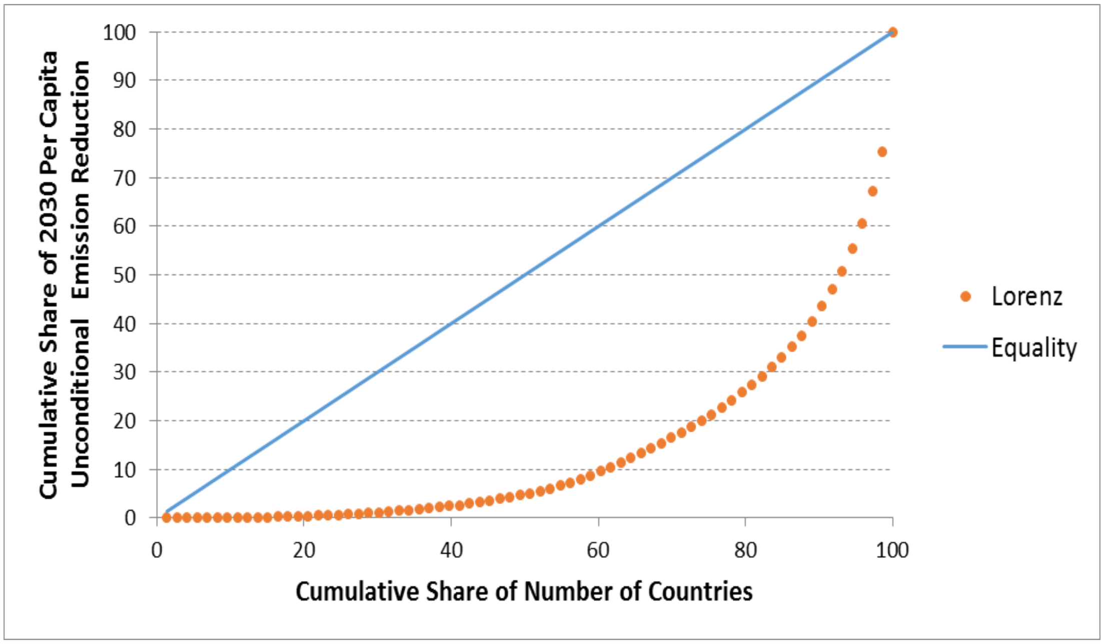

Figure 3. Lorenz Curve in Relation to Population, Country Equal Weighting (countries are ordered by per capita emission reduction commitments)

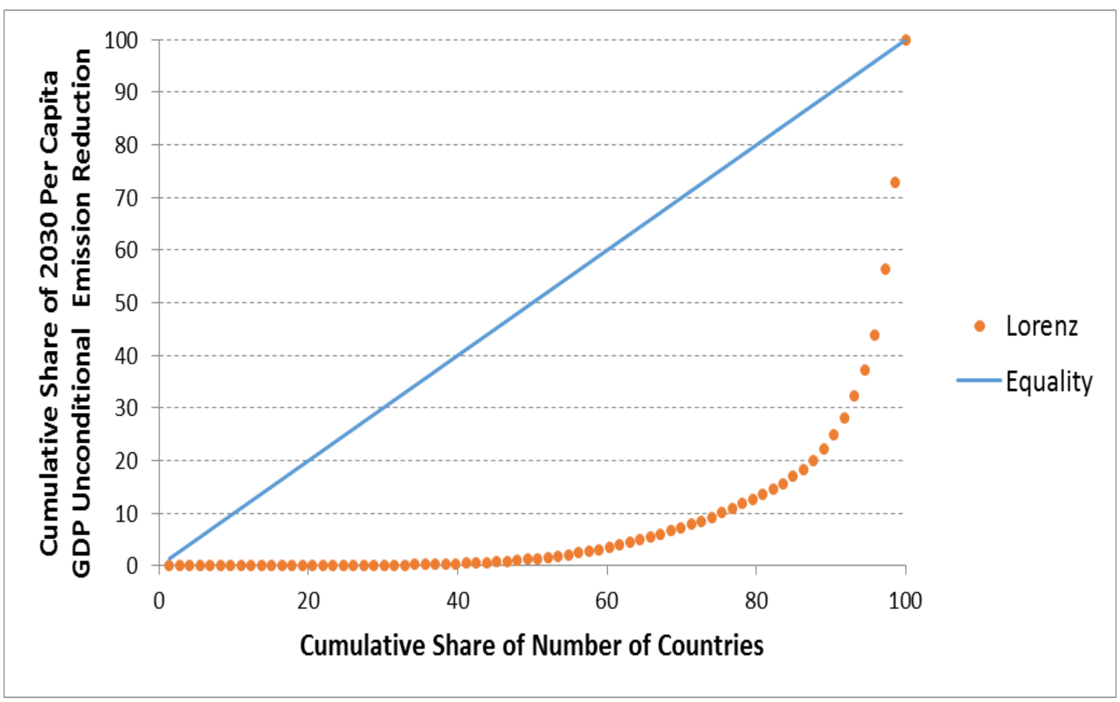

Figure 4. Lorenz Curve in Relation to Per Capita GDP, Country Equal Weighting (countries are ordered by per capita GDP emission reduction commitments)

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2. Atkinson Indexes

We also computed the Atkinson Index for the sample of countries in Table 1. This Index is considered superior to the Gini coefficient though it is less immediately transparent. It is also a single parameter measure of inequality, but it has a stronger basis in economic theory, particularly welfare analysis (Atkinson, 1970). The key parameter here is the "degree of inequality aversion", which represents the weight the society places on distribution inequality. This parameter affects the sensitivity of the Atkinson Index (AI) to income distribution inequalities. As the value of the parameter increases, the AI becomes more sensitive to changes in the income of the population at the lower end of the distribution (Braun, 1988; Du et al., 2015). The original Atkinson measure is based on a utility function of the following form:

$$U(y) = \begin{cases} \frac{y^{1-\varepsilon}}{1-\varepsilon} & \varepsilon > 0, \varepsilon \neq 1 \\ \ln(y) & \varepsilon = 1 \end{cases} \tag{1}$$

where *y* is personal income and ε is the inequality aversion parameter. When *y* increases, the utility increases at a diminishing rate. In our application, we replace *y* with *E*, which represents the per capita emission allowance as a result of COP21.[4] We believe it is reasonable to assume the utility function of per capita emission allowances has similar properties as the utility function in Equation (1), i.e., utility increases as people are granted more emission allowances but at a decreasing rate diminishing marginal utility. The Atkinson index (AI) is then defined by Equation (2):

$$AI = \begin{cases} 1 - \left[\sum_{i=1}^{n} \left(\frac{E_i}{\bar{E}_i}\right)^{1-\varepsilon} P_i\right]^{\frac{1}{1-\varepsilon}} & \varepsilon > 0, \varepsilon \neq 1 \\ 1 - \prod_{i=1}^{n} \left(\frac{E_i}{\bar{E}_i}\right)^{P_i} & \varepsilon = 1 \end{cases} \tag{2}$$

where E_i is the per capita emission allowance for country *i*, $\bar{E}$ is the average per capita emission allowance of all the sample countries, P_i is the population share of country *i*, *n* is the total number of countries in the sample. The value of the AI varies between zero and one, with a lower value of AI representing more equal distribution than a higher value of AI. The AI can also be interpreted in this way: if every country is granted the same level of per capita emission allowance, only 1-AI of the total emission allowances is needed to achieve the same level of social welfare that is obtained by the current distribution of the emission allowances (Hedenus and Azar, 2005).

In Table 2, we compute the AI for both the per capita emissions in the Business-as-Usual (BAU) scenario and the per capita emissions as a result of the COP21 pledges. The results indicate that when the ε has a lower value (i.e., lower inequality aversion, or less weight placed on the lower end of the distribution), the COP21 commitments result in a slightly higher AI or higher distributional inequality. However, when the value of ε increases above 1.5, the COP21 results indicate an improvement in distributional equality,

[4] This is computed for each country by subtracting the committed emission reduction target from the BAU emission level in 2030.

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but it is minimal. Essentially, the results indicate a worsening of the distribution of emissions following COP21.

Table 2. Comparison of Atkinson Index between the BAU Scenario and COP21 Scenario

ε	0.2	0.5	0.8	1	1.2	1.5	1.8	2.0
BAU Scenario	0.0508	0.1497	0.3106	0.4922	0.7329	0.9532	0.9899	0.9947
COP21	0.0531	0.1559	0.3194	0.5001	0.7366	0.9531	0.9897	0.9946

B. Equity Principle Analysis

We can also gain insight into the COP21 INDCs by comparing them with established equity principles. There is a general consensus among researchers about the equity principles relevant to international climate negotiations (see, e.g., IPCC, 1996; Kverndokk and Rose, 20089). Supplemental insight can be obtained by examining the following table of correlations between key variables (as presented in Table 3). The correlation results in GHG mitigation commitments absolute (level) terms indicate a very high and positive correlation between the emission reduction target and GDP, a moderately high positive correlation between the emission reduction target and population, and a very low but positive correlation between emission reduction target and per capita GDP. These results are consistent with our findings for the Lorenz curves and the Gini coefficients as discussed above. That is, the COP21 distribution of the emission reduction commitments among countries is most in line with the GDP levels of the countries than the population levels, and least in line with the per capita GDP level.

If we examine the correlations in terms of percentage GHG mitigation commitments, the numerical values differ somewhat. The correlation with per capita GDP is nearly the same as for the case of absolute levels. However, the population correlation differs significantly. In this case, it is negative, though near zero. We will see below that the interpretation is very similar, however, in relation to the role of population in fairness principles.

Table 3. Correlation of Key Variables

	2030 Unconditional GHG Reduction Target (in absolute terms)	Population	BAU Emission	GDP	Per Capita GDP
2030 Unconditional GHG Reduction Target (in absolute terms)	1				
Population	0.733	1			
BAU Emission	0.788	0.961	1		
GDP	0.951	0.754	0.786	1	
Per Capita GDP	0.168	0.031	0.075	0.185	1

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	2030 Unconditional GHG Reduction Target (in percentage terms)	Population	BAU Emission	GDP	Per Capita GDP
2030 Unconditional GHG Reduction Target (in percentage terms)	1				
Population	-0.018	1			
BAU Emission	-0.002	0.961	1		
GDP	0.105	0.754	0.786	1	
Per Capita GDP	0.233	0.031	0.075	0.185	1

Three of the most popular equity principles are Horizontal, Vertical, and Egalitarian equity. The first calls for all countries to have the same percentage emission reduction requirements on the “allocation” side, or equal proportional impacts on their GDP levels on the “outcome” side recall the definitions of these terms at the outset of this section. At this point, we can clearly see that the Horizontal equity principle is not operative in terms of allocation of emission reduction commitments. A distinction is sometimes made between Vertical equity and the Ability to Pay principle, with former being applicable to outcomes and the latter to initial allocations. This latter principle would call for countries with higher per capita GDP committing to higher percentage GHG reductions. However, the very low correlations indicate it is not operative.[5]

As to the egalitarian principle, historically this was favored strongly by developing countries, which usually have large populations and low per capita GDP’s. It was typically expressed in such a manner that more populous countries would have relatively lower emission reduction requirements and thus would receive the lion’s share of allowances. Essentially, this would be consistent with an inverse correlation between population and GHG emission reduction requirements, but the results in Table 3 indicate just the opposite in the case of commitment levels and a very weak correlation in percentage terms. Thus, we can conclude that COP21 resulted in a *shift* in the position of many developing countries. Essentially the position of populous developing countries in prior years was such that they would receive allowances in excess of their emissions, which implicitly meant a negative emission reduction requirement. However, these same countries might have found it embarrassing to state their commitments in these terms at COP21. Moreover, the historical position of industrialized countries to fend off being subject to the Vertical equity principle seems to have been attained in Paris when one looks at the low correlation between per capita GDP and emission reduction commitments.

Although commitments have been made, history has shown that not all countries view them as binding. In recent years, Canada and Australia, for example, have backed off of their Kyoto commitments. Knowledge of the equity implications of the COP21 commitments will be helpful in any future multi-

[5] The correlation between countries’ absolute levels of GDP and emission reduction level targets is very high, but this is not really related to either of the two aforementioned equity principles, but is rather more a function of country size.

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lateral revisions of the commitments, or in dealing with countries who threaten to back out of their commitments.[6]

III. Emissions Trading Model

A GHG emissions permit (allowance) trading system between the three regions is simulated using a variant of the NLP modeling framework of Rose et al. (1998) and Rose and Wei (2008). The model is of the following form:

minimize $TC = \sum_{i=1}^{n}[(a_i - b_i) \cdot R_i - b_i(1 - R_i)\ln(1 - R_i)] \cdot E_i$ (3)

where

TC ≡ total global abatement cost (endogenous)

R_i ≡ percentage abatement for country i (endogenous) $0 \le R_i \le 1$

E_i ≡ gross (unabated) CO_2 emission (in tons) for country i (exogenous)

α_i and b_i ≡ intercept and slope parameters of abatement cost function for country i (exogenous)

marginal cost function of the form: $a_i + b_i \ln(1 - R_i)$

subject to the following constraints:

$(1 - R_i)E_i - P_i \le \overline{P_i} \quad i = 1 \dots n$ (4a)

$\sum_{i=1}^{n} P_i = 0$ (4b)

where

$\overline{P_i}$ ≡ permit allocation for country i (exogenous)

P_i ≡ permit purchases or sales (in tons) for country i (endogenous)

IV. Emissions Trading Analysis

A. Basic Data

The model is applied to baseline data in Table 4 and to GHG mitigation cost curves for the trading entities, the basic form of which are presented in Figure 4. Our analysis below will modify these curves of macroeconomic considerations and alternative future scenarios for technologies having a major influence on GHG emissions.

[6] We have not addressed the equity implications of GHG mitigation across income groups within regions. Fro examples of such analyses, the reader is referred to Oladosu and Rose (2007) and Rauch et al. (2011).

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The migration cost curves in Figure 4 for the trading entities are first developed in step function form based on GHG reduction potential and per ton CO2e reduction cost data of individual mitigation or sequestration policy options obtained from a variety of sources. The curves for China come from McKinsey (2010), considered to be the most authoritative source for this country (see more details of this cost curve in Appendix A below). The EU cost curve was obtained from Wesselink and Deng (2009), who represent a consortium of European universities and other research institutions. The California curve was extrapolated from a study of Southern California by Wei and Rose (2014), which was based on careful analysis of mitigation costs by government agencies and an interdisciplinary research team. In order to use the cost curves in our NLP model, we fit smooth curves through the step functions using regression analysis (see the dashed curves in Figure 4). The fitted curve has the functional form of $MC = a + b \times \ln(1 - R)$. When we develop the smooth curve, we utilized the data points after the inflection point of the step functions _ to avoid biasing the portions of the cost curves relevant to the emissions trading (the portions above zero per unit cost).

Table 4. Basic Data

Trading Parties	BAU Gross Emissions in 2030 (million tCO_2e)	Emissions Cap in 2030 (million tCO_2e)	GHG Mitigation Goal in 2030 (relative to BAU emissions)	Autarkic Marginal Mitigation Cost (dollars per tCO_2e)
California	542	260	52.1%	151
EU	4,977	3,140	36.9%	94
China	20,036	17,974	10.3%	-6
Total	25,555	21,375	16.4%	

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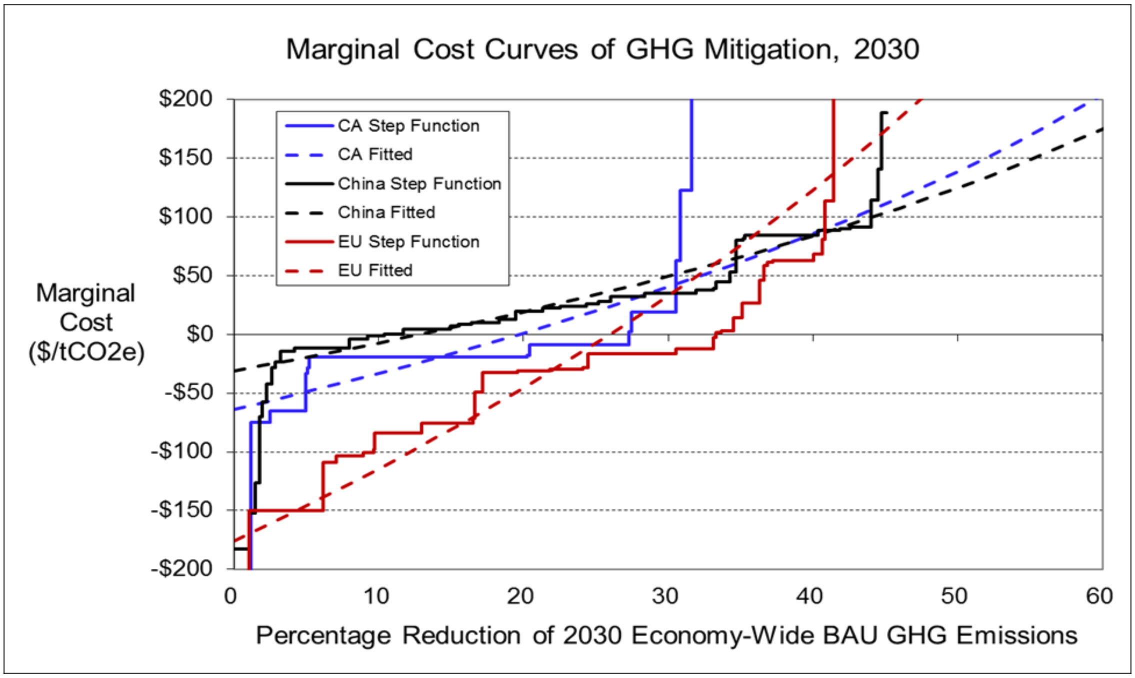

Figure 4. Marginal Cost Curves of GHG Mitigation for California, EU, and China in 2030

B. Base Case Analysis

The results of our base emissions allowance trading case are presented in Table 5. Before trading, the mitigation costs for China and EU are negative, given the relatively low emission reduction target for the former and the extensive range of cost-saving options (primarily energy efficiency, recycling, cogeneration, and land-use planning) for the latter. The pre-trading mitigation cost for California is positive, primarily due to its high emission reduction target. Also, it has a relatively steep marginal cost curve compared with China and smaller cost-saving mitigation capability compared with EU. The total mitigation cost for the three entities before trading is actually about $125 billion in cost savings (due primarily to the adoptions of energy efficiency and land-use policies. Trading results in even more cost-savings, totaling $38 billion in 2030, consistent with the implications of the Coase Theorem. China sells 701 million permits, most of which are purchased by the EU at equilibrium permit price of $2.46/ton$CO_2$e. Accordingly, the EU obtains greater cost savings ($23.4 billion) from its allowance purchases than does California ($11.7 billion). Even though the allowance purchase by California enable it to reduce its original mission reduction goal from 52.1 to 20.3%, while the EU reduces its emission reduction goal from 36.9 to 26.3%, the latter reaps a greater cost savings because it's marginal cost of mitigation curve is relatively much steeper. In fact, the EU's net gains are 100% greater than that of California. Moreover, the EU gains are more than 7 times that of China, primarily because the margin between the permit price and its increased mitigation costs is rather low for the latter.

Table 5. Economy-Wide Emission Trading Simulation among California, EU, and China in Year 2030 Based on <u>Micro</u> Cost Curves

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(million dollars or otherwise specified)

Trading Parties	Before Trading	After Trading			Cost Saving	Permits Traded	Emission Reduction After Trading		Original Emission Reduction Goal
	Mitigation Cost	Mitigation Cost	Trading Cost[a]	Net Cost		(million tCO_2e)	(million tCO_2e)	(percent from BAU)	(percent from BAU)
California	8,636	-3,537	423	-3,113	11,749	172	110	20.3	52.1
EU	-94,633	-119,330	1,298	-118,032	23,398	528	1,308	26.3	36.9
China	-38,979	-40,410	-1,721	-42,131	3,152	-701	2,762	13.8	10.3
Total	-124,977	-163,276	0	-163,276	38,299	701[b]	4,181	16.4	16.4

[a] Permit Price = $2.46/ton$CO_2$e.

[b] Represents the number of permits bought or sold.

C. Macroeconomic Cost Analysis

Many analyses are performed with engineering-based, or microeconomic, GHG mitigation cost curves (see, e.g., Rose et al., 1998; Ellerman, 1999). However, given strong interdependencies in most nations' economies and the significant cost of mitigation, this approach is likely to understate the total impacts of mitigation. For example, studies have found that urban forestry (tree planting to sequester carbon) has a relatively high direct cost per unit mitigated, while a renewable portfolio standard (RPS) has a relatively lower, but still positive, cost. Because an RPS pertains to electricity production, the increased cost ripples through the economy and multiplies several-fold, leading to a potentially significant negative macro impact (Wei and Rose, 2014). On the other hand urban forestry is at the very end of the production stream and does not conjure a demand price, so hence has very limited multiplier or general equilibrium effects. Our analysis indicates that the relative positioning of these 2 options switches when one considers the macro implications. The adjusted macroeconomic cost curves for the three trading entities are presented in Figure 5.

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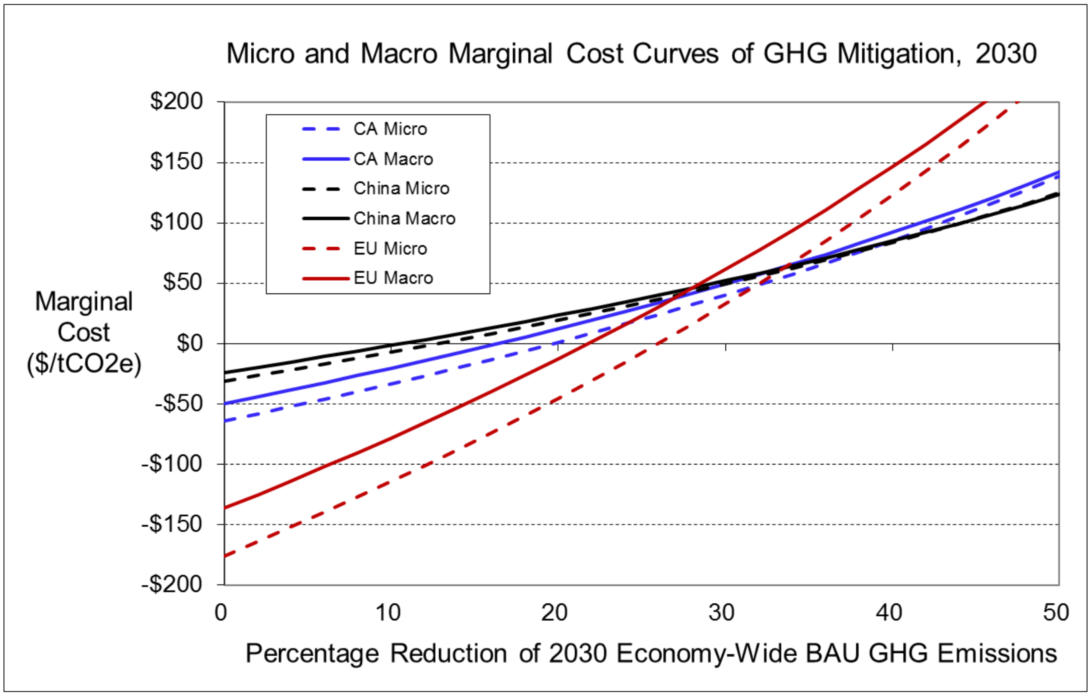

Figure 5. Micro and Macro Cost Curves for China, EU, and California

The macroeconomic cost curves in Figure 5 are constructed based on the relations between the macro- and micro-level cost curves developed in Wei and Rose (2014) for the Southern California Region. Marginal cost curves at both the micro and macro levels are constructed and compared for the study region, and the macro to micro ratios for both the intercept coefficient and the slope coefficient in the marginal cost functions are computed. The same ratios are applied to the coefficients in the micro marginal cost functions for China, EU, and California to obtain the corresponding macro cost curves as depicted in Figure 5.

Table 6 presents the results of emissions trading based on the macro level cost curves. When we take into consideration the total cost (including both direct and indirect costs) of mitigation options, the equilibrium permit price increases from \$2.45/CO2e in the Base Case to \$9.63/CO2e in this case. China again is the permit seller, while EU and California are the buyers. EU obtains greater cost savings from its allowance purchases than does California. Both of them obtain cost savings greater than China from trading.

Compared to the microeconomic cost results presented in Table 5, the results of taking macroeconomic considerations into account indicate lower cost savings pre-trading, but more permits traded and greater per unit gains from trade. Of course the overall emission reductions are the same but not surprisingly the emission reduction by CA and EU have decreased and that of China has increased relative to the results of the microeconomic cost curve case.

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For completeness, we mention the transfers, primarily from industrialized countries who committed to the COP21 Accord, totaling approximately $100 billion, to go to developing countries. However, these pertain to the conditional commitments made in Paris, and we have confined our focus to the unconditional commitments, for which the transfers are not relevant.

Table 6. Economy-Wide Emission Trading Simulation among California, EU, and China in Year 2030 Based on Macro Cost Curves

(million dollars or otherwise specified)

Trading Parties	Before Trading	After Trading			Cost Saving	Permits Traded	Emission Reduction After Trading		Original Emission Reduction Goal
	Mitigation Cost	Mitigation Cost	Trading Cost[a]	Net Cost		(million tCO_2e)	(million tCO_2e)	(percent from BAU)	(percent from BAU)
California	11,291	-2,200	1,716	-484	11,775	178	104	19.3	52.1
EU	-34,052	-76,678	6,583	-70,095	36,043	684	1,153	23.2	36.9
China	-25,952	-22,194	-8,299	-30,492	4,541	-862	2,923	14.6	10.3
Total	-48,712	-101,072	0	-101,072	52,359	862	4,181	16.4	16.4

[a] Permit Price = $9.63/ton$CO_2$e.

[b] Represents the number of permits bought or sold.

C. Analysis of Alternative Technology Paths

Advances in the extraction and transformation of primary energy resources and of GHG mitigation and sequestration options have potentially prominent implications for the direct cost of achieving climate policy goals. We will analyze technological advances in renewable energy, energy efficiency, and carbon capture and storage. The future of these technological changes is highly uncertain, but sensitivity analyses can be performed to analyze the potential impacts in aggregate and across nations. We will examine the equity implications of alternative outcomes. This will reveal the potential to improve the well-being of the relatively disadvantaged countries through possible redirection of research and development in various technological alternatives.

Figure 6 presents the cost curves under one example alternative technology path -- a technology-limiting scenario with respect to carbon capture and storage (CCS). In this alternative scenario, we exclude CCS from the portfolio of mitigation options.[7] Since California has very limited CCS potential, and this mitigation option has not been included in the original cost curve used for the base case, the cost curve for California remains the same. For China and the EU, the marginal cost curves shift to the left when we exclude the CCS options from the mitigation technology portfolio.

[7] This is one of the alternative technology scenarios (NoCCS) analyzed in the Stanford Energy Modeling Forum (EMF) Study 27 (Kriegler et al., 2014).

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Table 7 presents the results of emissions trading based on the technology path adjusted cost curves. As both the cost curves for China and EU move slightly to the left after we exclude CCS from the mitigation technology portfolio, the equilibrium permit price increases slightly from $2.45/CO2e in the base case to $3.13/CO2e in this case. Compared to the base case results presented in Table 5, the results of the alternative technology path scenario indicate slightly lower cost savings pre-trading, but more permits traded and greater per unit gains from trade. As the cost curves for China and EU become slightly steeper, these countries would decrease their emission reduction, while CA would increase its emission reduction relative to the base case. However, both China and EU obtain higher gains, while CA obtains lower gains from trading compared with the base case.

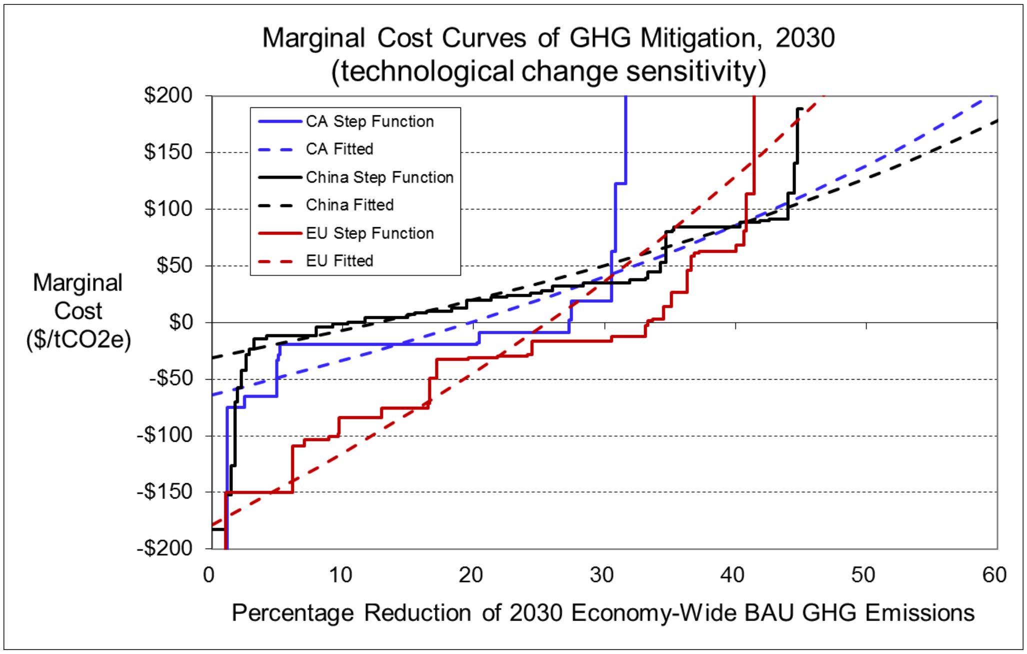

Figure 6. Marginal Cost Curves of GHG Mitigation for California, EU, and China in 2030 (excluding CCS from mitigation technology portfolio)

Table 7. Economy-Wide Emission Trading Simulation among California, EU, and China in Year 2030 Based on Technology-Adjusted Micro Cost Curves

(million dollars or otherwise specified)

Trading Parties	Before Trading	After Trading			Cost Saving	Permits Traded	Emission Reduction After Trading		Original Emission Reduction Goal
	Mitigation Cost	Mitigation Cost	Trading Cost[a]	Net Cost		(million tCO_2e)	(million tCO_2e)	(percent from BAU)	(percent from BAU)
California	8,636	-3,534	537	-2,997	11,632	171	111	20.5	52.1
EU	-92,760	-119,534	1,692	-117,841	25,082	540	1,297	26.1	36.9
China	-38,628	-39,704	-2,229	-41,933	3,305	-711	2,773	13.8	10.3

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Total	-122,752	-162,771	0	-162,771	40,019	711	4,181	16.4	16.4

[a] Permit Price = \$3.13/tonCO_2e.

[b] Represents the number of permits bought or sold.

V. Post-Trading Equity Analysis

We now compare the post-trading equity outcome with the pre-trading equity analysis of INDCs. This is made difficult because we only have 3 countries thus far in our emissions trading simulations (Reviewer: we plan to include all countries in the analysis by the time of the Conference). However, we can gain some general insights that enable us to generalize our results to the 73 countries in Table 1 that have positive unconditional GHG reduction commitments.

To evaluate the equity of COP21 after GHG emissions allowance trading, we focus first on the results in Table 5, our base case. We see that the countries/regions with the highest current GDPs (see Table 1) reap the greatest rewards of trading. California's GHG mitigation cost improves 150% to the point where it transitions to net cost-saving. The EU's mitigation cost improves by only 25%, and China's by less than 10%. For the macroeconomic case in Table 6, California's and the EU's mitigation costs improved by 100% each, but China's by less than 20%. The predominant shares of the post-trading gains go to the more well-off regions again, counter to Vertical equity. These results could generalize to all 73 countries because CA and the EU are representative of the vast majority of the other industrialized counties in our sample in terms of level of economic development, gross emissions, and absolute and percentage mitigation commitments. China is atypical of developing countries because of its larger levels of GDP, emissions and emission reduction commitments; but since it is predicted to capture a lesser proportion of the gains from emissions trading than CA and the EU, most of the other developing countries are likely to do so as well.

On a per capita GDP basis, California's gains are the highest and China's the lowest under both the micro and macro analyses. Again this means a worsening of Vertical equity.

The results also have negative implications for the Egalitarian equity principle. The gains are inversely correlated with population and are positively correlated with per capita GHG emissions. Again these results will generalize to an analysis of all 73 countries in our sample.

Note also that these results are little affected by the alternative technology scenario presented in Table 7, despite the fact that technology change would have a differential effect across the three regions. This is likely to be the case for any single technology change, since few individual technologies outside of electricity generation and motor vehicles generate more than 10 percent of GHGs.

VI. Conclusion

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We have analyzed the equity implications of the COP21 Accord negotiated in Paris in December 2015. Our analysis is performed in two parts. First, we analyze the initial *allocation* of voluntary GHG reduction commitments directly (before any emissions allowance trading) by using correlation analysis, and computing Gini Coefficients and Atkinson indexes. Then we simulate the effect of trading for sample of countries to analyze the *outcomes* of the Paris Accord in in terms of cost implications in relation to country GDP and population.

Our analysis indicates that the GHG reduction commitments made at COP 21 run counter to major equity principles such as Ability to Pay, Vertical, Horizontal, and Egalitarian equity. They are definitely a major departure from the Egalitarian, Vertical, and Rawlsian equity principles proposed for many years by developing countries.

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Appendix A. Marginal Mitigation Cost Curve for China, 2030

The marginal abatement cost (MAC) curve for China is based on the McKinsey study (McKinsey, 2009), which evaluated the emission reduction potentials and associated economic costs of over 200 efficiency and GHG mitigation technologies and strategies in China.

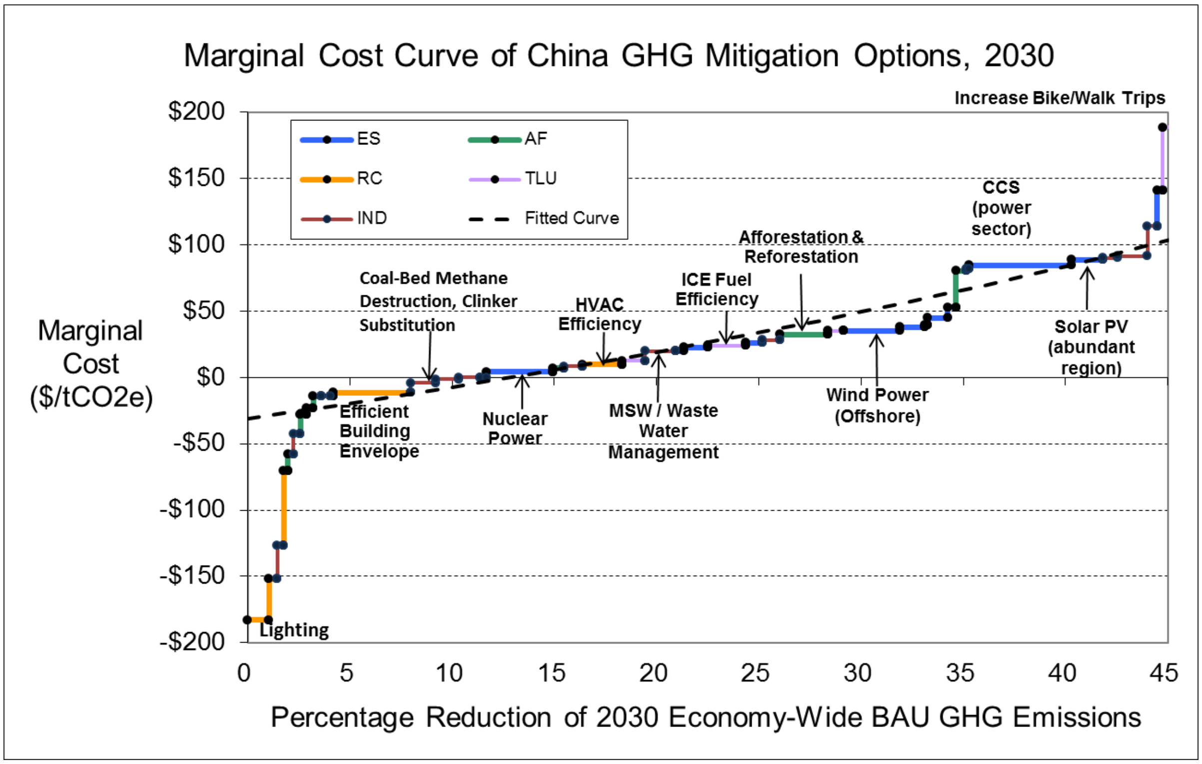

Figure A1. Stepwise and Fitted Marginal Cost Curve for China, 2030

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