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Reallocate CO_2 emission reduction after Kyoto: global management with efficiency and equity

Abstract

The authors propose a reallocation criterion to increase CO_2 reduction efficiency and ensure equity for existing Annex B countries in the Kyoto Protocol and for Annex B countries along with four developing and newly industrialized countries, China, India, South Korea, and Taiwan. This study utilizes data across 52 countries over 1990-2003. The results show that high income and high inequality countries are urge to implement emission reduction properly by assigning higher weight of reduction percentages. Similarly, low income and low inequality countries confront analogous situations as high income and high inequality countries. As such, a relative efficient CO_2 emission reduction will be generated globally. That is, with such reallocation criterion, total CO_2 emission reduction reduces 17.28% more than that if all 32 Annex B countries meet their current reduction commitments. Likewise, the total CO_2 emission reduction increases another 8.54% when China, India, South Korea, and Taiwan are included among the potential commitment countries array. The authors conclude that inclusion of income inequity in the reduction percentage does not only achieve relatively efficient global emission reduction but also provide incentives to countries with different stages of economic development to further emission commitment negotiation.

Keywords: economic development, Gini coefficient, marginal emission tendency of income, panel data.
JEL Classification: O44, Q54, Q56.

Introduction

Ever since the industrial revolution, the fossil energy has been the most crucial energy resource, which leads to rapid economic development of many developed countries nowadays. Among the greenhouse gases, carbon dioxide (CO_2) takes 66% and has the highest share among all greenhouse gases. Its influence to the greenhouse effect is the greatest and it also leads to the irreversible climate variance and makes the survival of mankind and economic environment encountered serious threat (Stix, 2006). In addition, the influence of greenhouse gases, different from other contaminations, is global with feature of long-term accumulation. It is thus clear that the international conformity and long-term cooperation effort is essential to control such emission.

As such, the 1992 Rio of Brazil started tackling the problems and numerous countries committed to reduce CO_2 emission at the Kyoto Protocol in the third conference of the parties in 1997. The six greenhouse gases, including CO_2, have to reduce an average 5.2% emission level of 1990 during 2008-2012 as target (United Nations, 2007). Thus control of CO_2 emission to the minimum becomes prudent problems for many countries.

Implementation of international cooperation, however, always confronts complex problems. This is also the reason why the Kyoto Protocol is not effective until 2005 although it was ratified in 1997. Nordhaus (2001) criticizes that current emission reduction commitment percentages of Annex B countries, mainly based upon the economic development and emission statuses, are in the condition of deficient information. That is, more concern is toward the efficiency of emission abatement (Brandt, 2003). However, in addition to achieving the principle of efficiency, gratifying certain equity principles is debating and arguing frequently among the countries (Strazicich and List, 2003). Continuously searching for efficient and equitable emission reductions among countries is essential for such cooperation to implement furthermore (Ringius et al., 2002). The principles of equity for distributing emission reduction have been deliberated in various studies and one of the concepts of equity is the responsibility of slowing CO_2 emission by developed countries (Berk and Elzen, 2001; Höhne et al., 2003; Tonn, 2003).

However, most developing or underdeveloped countries, especially for those countries with high income development like India, China and part of newly industrialized countries like South Korea and Taiwan, are still not under limitation. It is believed that the developing countries will be the major greenhouse gases makers in the coming years (Böhringer, 2003; Socolow and Pacala, 2006). On one hand, this will further complicate the existing emission reduction commitment controversies for the Protocol. On the other hand, this will drive the related countries aspire to foresee the emission reduction allocation commitment with a relative complete involvement of equity and efficiency.

It is expected that the emission reduction commitment of developing countries, while beyond the basic need development stage, will be brought into negotiation in the future. Meantime the cultural difference, social system, and variation degree of politics might be more extensively considered than before. As such, it is necessary to consider a relative comprehensive view of equity other than a view with economic development only while upcoming committed emission reduction of CO_2 is prepared by the year of 2012. The influence of income inequality firstly brought forward by Boyce in 1994 was to obtain an ideal inversed U-shaped relationship between income level and environmental pollution. The argument of Boyce was approved by subsequent empirical results in a similar objective (Magnani, 2000; Ravallion et al., 2000). However, without taking into account both the level of economic development and income distribution, the effect of income inequality to CO_2 emission does not play any active role in allocating CO_2 emission reduction percentage among countries presented in the existing research.

As such, the purpose of this study is to reallocate CO_2 emission reduction commitment percentage for existing Annex B countries in the Kyoto Protocol and four developing, newly industrialized countries, i.e. China, India, South Korea, and Taiwan with and without concern of the view of income inequity. The relationship between CO_2 emission reduction and economic development and that among CO_2 emission reduction, economic development, and income inequality is constructed to operate such idea. A newly, accessible, and complete set of data of 52 countries in the year of 1990-2003 is collected for such purpose. Among 52 sample countries, there are 32 countries categorized in Annex B countries of the Kyoto Protocol in which with the exception of the United States and Australia 30 countries have emission reduction commitment. The total CO_2 emission of these 32 countries takes approximately 99% of total 38 countries in the Annex B countries of the Kyoto Protocol.

1. Methods and materials

1.1. Connection of income inequality, economic development, and CO_2 emission. Since the relationship between economic development and income inequality firstly discovered by Simon Kuznets in 1955 one of the possible explanations of that inverted-U relation between income distribution and economic level is that part of population employed by agricultural sector is transferred to industrial sector at the initial stage of economic development and thus the income gap between sectors is enlarged. The subsequent literature has consistently approved in succession that income distribution and income reveals an inverted U-shaped relation when economic structure of a nation is transferring from agriculture to industry (Jha, 1996; Zilio and Recalde, 2011; Cox et al., 2012; Franklin and Ruth, 2012).

Later literature, however, finds that income and income inequality relationship in many developed countries takes an ascending trend since 1960s (Tribble, 1999). This implies that income distribution would not necessarily get even while income reaches certain level. The possible interpretation of this phenomenon is that the developed countries are facing another economic structure by transfer from industrial sector to service sector (Gallet and Gallet, 2004). Another view justifies this second enlargement of income distribution lies in the advancement of technology of the developed countries. Due to the renovation of technology, the income gap between high technology and low technology sectors enlarges gradually, which leads to the expansion of domestic income gap. Consequently, more people are transferring from the low technology sectors to the high technology sectors then income distribution may resume to a relatively equal status again (Aghion et al., 1999).

Furthermore, the relationship between economic development and environmental quality or pollution emission firstly appeared in World Development Report of World Bank in 1992. Since then the literature has subsequently demonstrated that the pollution of some contaminations will increase with economic development, and the resource can be transferred to resolving environmental problem when the economy has developed to a certain level (Shafik, 1994; Selden and Song, 1994; Grossman and Krueger, 1995; Ravallion et al., 2000; Heerink et al., 2001). Moreover, Ravallion et al. (2000) observe that the marginal consumption tendency of high income countries on fossil energy is different from that of low income countries and the consumption activity and the direct or indirect demand of citizens on fossil energy are then influenced by income distribution accordingly.

Boyce (1994) is the first scholar introducing income distribution into the discussion of economic development and pollution. This provides a possible delicate linkage among income, income distribution, and environmental quality. Boyce's research makes use of the viewpoint that the unequal allocation of social power will affect environmental quality to certain degree. This explains the association of income inequality and environmental quality within country due to different preference of environmental quality and power allocation between the poor and the rich.

It is found that income inequality will be eradicated with the development of economy and many literatures have evidenced the positive relationship between economic growth and CO_2 emission. Therefore, it can be deduced that CO_2 emission of high income countries with low inequality will be low while CO_2 emission of low income countries with high inequality tends to be high. That is, high income inequality is detrimental to CO_2 emission reduction. However, contradictory results have observed from the studies done by Ravallion et al. (2000), Heerink et al. (2001), and Hill and Magnani (2002) in which the inequitable income distribution is beneficiary to the reduction of CO_2 emission.

Moreover, the shock to low income countries was usually larger than that to high income countries after emission reduction is enforced (Hamilton and Cameron, 1994). And unequal income distribution of a country will make emission reduction cost higher than that with equal income distribution (Hamilton and Cameron, 1994). Since the enlargement of income inequality has different influence to the countries in different development stages, the influence of income inequality to the relationship between economic development and CO_2 emission for countries in different development stages is also different. It will thus be inappropriate to adopt one conclusion to portray the relationship between income and income distribution among different development stage of countries while equity is emphasized.

1.2. Variables selection. In order to analyze the relationship between CO_2 emission and income distribution for countries with different status of economic development along time trend, assembling appropriate data and representative variables is necessary. Under the scope of macroeconomics, per capita data are collected from the database of United Nations Statistics Division (2007). All the variables in this database are in nominal form and thus needed to be deflated by 1990 price level to eliminate the impact of inflation. As with the emission of CO_2, it is noted that total CO_2 emissions of a country is highly related to the amount of population. Thus per capita CO_2 emissions to eliminate the impact of country population are adopted (Friedl and Getzner, 2003). The per capita CO_2 emission data from the Oak Ridge National Laboratory (ORNL) in Tennessee are the most consistent and comprehensive source for CO_2 emissions over time and across countries. The emissions of CO_2 are annually projected levels for each country and are based upon the reference approach proposed by Intergovernmental Panel on Climate Change (IPCC).

In order to make the cross countries income inequality comparison meaningful, Gini coefficients assembled by World Institute for Development Economics Research (WIDER) with a modification accomplished by Deininger and Squire (1996) as the data bank of World Income Inequality Dabase V2.0a (WIID) are used for this purpose (World Institute for Development Economics Research, 2007). A few missing Gini coefficients are appropriately replaced by the adjacent years to make the dataset complete due to the slow and steady shift of income structure justified by Aaron (1978).

In addition to economic development, CO_2 emission, and income inequality, there are other factors influencing CO_2 emissions. Those are population density and industrial structure. Population density, collected from World Bank, can be a meaningful indicator to measure the magnitude of pollution. The regions with high population density normally cause more environmental pollution than that from the area with low population density (Selden and Song, 1994; Scrugges, 1998). Furthermore, percentage manufacturing share of GDP, collected from the United Nations Statistics Division database, can depict the influence of industrial structure change in CO_2 emissions. In general, countries with higher manufacturing shares of GDP will usually have more CO_2 emissions than those from the lowers (Grossman and Krueger, 1995).

Taking account of the necessary attributes and limitations of variables of income inequality, economic development, and CO_2 emissions, the final analyzed data are a combination of time series of 1990 and 2003 and of cross-section of 52 counties. There are 728 observations in total. Among these, 32 countries are Annex B countries of the Kyoto Protocol and 30 of them, except the United States and Australia, who have committed to reduce greenhouse gas emission[1]. The amount of CO_2 emissions of these 52 countries in these 14 years takes about 80.47% of global total emissions.

1.3. Model specifications. As regard to the estimation, OLS is inappropriate for a pooling of 14 years time-series and 52 countries cross-sectional data. Therefore, fixed-effect and random-effect models for panel data are utilized. The first model does not take the income inequality into account. To measure the impact of income inequality, the second model is incorporated with the interaction of per capita GDP and income inequality variable of Gini coefficient. In addition to income inequality variable (*Gini*) and income development (*GDP*), the population density (*Dens*) is a critical factor which affected economic activity and environmental quality largely (Selden and Song, 1994; Scrugges, 1998). Moreover, variable of manufacturing share of per capita GDP (*Manu*) represents the result of industrial transfer to CO_2 emission (Grossman and Krueger, 1995). Time trend variable (*Time*), a proxy of technical progress, is used to reflect the technical effect both for production and pollution prevention program along time (Shafik, 1994; Ravallion et al., 2000).

The cubic forms listed below are specified for both models to capture the most variation of *N* relationship for CO_2 emission and per capita GDP only and for CO_2 emission and per capita GDP and income inequality:

[1] The committed emission reduction countries in Annex B of the Kyoto Protocol not included in this analysis are Croatia, Iceland, Liechtenstein, Monaco, New Zealand, and Switzerland.

$$(CO_2)_{it} = \beta_{1i} + \beta_2 GDP_{it} + \beta_3 GDP_{it}^2 + \beta_4 GDP_{it}^3 + \beta_5 Dens_{it} + \beta_6 Manu_{it} + \beta_7 time + \varepsilon_{it}, \quad (1)$$

$$(CO_2)_{it} = \beta_{1i} + \beta_2 GDP_{it} + \beta_3 GDP_{it}^2 + \beta_4 GDP_{it}^3 + \beta_5 Dens_{it} + \beta_6 Manu_{it} + \beta_7 Gini_{it} + \beta_8 Gini_{it} * GDP_{it} + \beta_9 time + \varepsilon_{it}, \quad (2)$$

where i is a country index, t is a time index, ε_{1i} is the random error. $ß_{1i}$ is the individual difference of i country and it is caused by some intrinsic traits of the country, such as fossil fuel price and efficiency, the energy policy of the government, and the consumer priority. These traits would affect CO_2 emission over the years. Hence, $ß_{1i}$ is a specific constant, which would not fluctuate along the years.

As equation (2) shows, the impact of income inequality (*Gini*) on CO_2 emission composes both the direct and the indirect effect as follows:

$$\frac{\partial (CO_2)_{it}}{\partial Gini_{it}} = \beta_7 + \beta_8 GDP_{it}. \quad (3)$$

Equation (3) indicates if coefficients $ß_7$ and $ß_8$ have the same signs then increasing income will reinforce CO_2 emissions through effects of income inequality. On the contrary, if they have opposite signs then increasing per capita GDP with accounting for inequality will switch the impact direction on CO_2 emissions. Furthermore, a threshold income level can be generated to determine the impact of income inequality on CO_2 emission while these two coefficients have opposite signs.

2. Results and analyses

All estimated results demonstrate that the F test in fixed effect models and LM test in random effect model are significant. In addition, the results of Hausman χ^2 test show that fixed effect model in all models have better performance than its counterparts of random effect models. As a result, results presented in Table 1 are from fixed-effect model and thus will be adopted for further analysis hereafter.

Table 1. Estimation results of two models

Variable	Model with income only	Model with income and income inequality
GDP	289.540***	207.609***
	(44.32)	(45.09)
GDP^2	-5.830***	-7.588***
	(1.75)	(1.74)
GDP^3	0.045**	0.044**
	(0.02)	(0.02)
Dens	8.691***	8.260***
	(1.54)	(1.49)
Manu	16.672***	12.407***
	(3.51)	(3.49)
Gini	-	-17.493***
	-	(4.38)
*Gini*GDP*	-	3.477***
	-	(0.50)
Time	-21.546***	-20.265***
	(3.93)	(4.00)
Constant	-	-
	-	-
Adj. R^2	0.962	0.965
F-value	327.46	339.71
Hausman χ^2	54.21	63.35

It is found that the relationship between CO_2 emissions and per capita GDP have good statistics performance for model with accounting for income level only. There is significantly negative relationship between income inequality and CO_2 emission for model considering both income level and inequality. Therefore, there indeed exists a relationship between income inequality and CO_2 emission. The results further show that the coefficients of income inequality and the interaction of income and income inequality have opposite signs. This indicates that the relationship between income inequality and CO_2 emission varies by income levels. Per capita GDP at US$ 5,031.061 is the demarcation level for the relationship between income inequality and CO_2 emission to switch their relationship. That is, uneven income inequality will bring higher CO_2 emission.

The configuration of reallocation percentage with no income inequality can be derived from equation (1).

This is considered as the increase of CO_2 emission resulted from the change of per capita GDP and can be treated as the marginal emission tendency of income shown in equation (4) and denoted as *A*:

$$\frac{\partial (CO_2)_{it}}{\partial GDP_{it}} = \beta_2 + 2\beta_3 GDP_{it} + 3\beta_4 GDP_{it}^2 = A. \quad (4)$$

On the other hand, when income inequality is included the marginal emission tendency of income, derived from (2), is computed as equation (5) and denoted as *B*:

$$\frac{\partial (CO_2)_{it}}{\partial GDP_{it}} = \beta_2 + 2\beta_3 GDP_{it} + 3\beta_4 GDP_{it}^2 + \beta_8 Gini_{it} = B. \quad (5)$$

The marginal emission tendency of income for a specific country i, designated as A_i, to the summation of marginal emission tendency of income for all the countries $\sum_{i=1}^{n} A_i$ without the influence of income inequality is used as a percentage adjustment for that country shown as equation (6). Similar idea applies to the percentage adjustment while income inequality is considered and it is shown in equation (7).

$$\left[\frac{\partial CO_{2_i} / \partial GDP_i}{\sum_{i=1}^{n}\left(\partial CO_{2_i} / \partial GDP_i\right)}\right]_{Unconsidering\ the\ income\ inequality} = \frac{A_i}{\sum_{i=1}^{n} A_i} = \alpha, \quad (6)$$

$$\left[\frac{\partial CO_{2_i} / \partial GDP_i}{\sum_{i=1}^{n}\left(\partial CO_{2_i} / \partial GDP_i\right)}\right]_{Considering\ the\ income\ inequality} = \frac{B_i}{\sum_{i=1}^{n} B_i} = \beta. \quad (7)$$

As a result, with consideration of income distribution the new emission reduction commitment percentage for the country with per capita income above US $5,031.061 is the current emission reduction percentage commitment of that country adding the difference between (ß – α). On the other hand, for those countries with per capita income below level of US $5,031.061 the reallocated emission reduction commitment percentage is the current emission reduction percentage commitment of that country subtracting the difference between (ß – α).

The above reallocation formula demonstrates if Gini coefficient in the marginal emission tendency of income is positive in equation (5) then the country with relative even income distribution has higher marginal emission tendency in the condition that the income inequality is considered. This will result a higher magnitude of ß – α. Therefore, there is a tendency to underestimate the marginal emission tendency for the country with unequal income distribution while income inequality is not accounted for.

2.1. The reduction commitment percentage with income inequality and income level. The current emission reduction percentage and the emission levels for 32 Annex B countries are presented in Table 2 (see Appendix). The corresponding change of emission reduction percentage with consideration of income level and income inequality will, therefore, be computed. Since the dividing per capita GDP threshold is US$5,031.061 this level has turned the relationship of income inequality and CO_2 emission from negative correlation to positive correlation. As a result, 32 countries are divided into high and low income group based upon per capita GDP of US$5,031.061 for new emission reduction percentage to be allocated. Accordingly, there are 11 countries categorized as low income countries and 21 countries classified as high income countries.

As with low income country group, the enlargement of income distribution gap will influence the economic development significantly and the influence of income inequality to social stability is much more than that of the high income countries. Therefore it is suitable and rational to subtract ß – α from current marginal emission tendency of income for those countries when income inequality is accounted as a new emission reduction percentage factor. Those recalculated emission reduction percentages and the total emission reductions are shown in Table 2.

Among these 11 countries, income distributions of Czech, Hungary, Romania, and Slovak Republic are more relatively equal than the other 7 countries. The emission reduction percentages for these 4 countries will be higher than current committed emission reduction percentages after reallocation. That is, the reallocated emission reduction percentage is undertaken by low inequality countries in low income group. As compared to the other countries at the same income group, these 4 countries with relatively equal income distribution have ability to tolerate heavy shock of emission reduction after reallocation. On the contrary, while per capita GDP reaches to certain level, the relationship between income inequality and CO_2 emission per person will turn to positive, which indicates that the relative even income distribution will create less CO_2 emission.

For those countries with per capita GDP higher than US$ 5,031.061, the marginal emission tendency of income will increase if income distribution gets unequal. This implies the main industrial structure of these countries will not only expand the income gap but also make use of energy efficiency lower than those countries with the same income levels. Therefore adding $ß - \alpha$ to current emission reduction percentage is to warn these countries and urge them to improve the energy efficiency or implement relatively efficient emission reduction solution.

The high income country group indicates that the stricter emission reduction percentages are assumed by the countries with uneven income inequality such as Greece, Portugal, and the United States. Denmark, Ireland, Italy, Spain, Slovenia, and the United Kingdom are the other 6 countries that have similar occurrences. This indicates that although these countries are categorized in the group of high income countries, taking into account income inequality means that countries with a high-inequality will emit more CO_2 emission per person for each unit of GDP generated. Therefore, taking into account income inequality increases the emission reduction percentages for these countries and also provides a relative efficient way to achieve the total CO_2 emission reduction target globally. The emission reduction percentages of each country before and after the reallocations are presented in Table 2.

2.2. Emission reduction commitment with India, China, South Korea and Taiwan. The most disputable large CO_2 emission from countries like China, India, South Korea, and Taiwan who has not yet committed the CO_2 emission reduction will be brought into analysis under such reallocation arrangement. There is difference in income levels among these 4 countries. Since China and India have relatively low per capita GDP and those levels are lower than the estimated threshold level of US$ 5,031.061 then these two countries are classified in the country with low income group. South Korea and Taiwan, on the other hand, have relatively high per capita GDP and these levels are higher than the threshold level. These two countries are then categorized in the high income group. Following the similar rule designed above, if China and India reduce 4.5% and 5.1% respectively below the level of 1990. The counterpart of high income countries, South Korea and Taiwan have relatively high obligation to reduce the emission by 7.24% and 6.19%, respectively.

While bringing into 4 potential newly reduction targeted countries, 8 countries, such as Denmark, among the original 21 high income group of Annex B bear higher pressure of emission reduction percentage than their currently commitment due to their inequitable income distribution. The inequitable income distribution will on the contrary make 4 countries, such as Bulgaria, among the current 11 low income group countries release their emission reduction commitment pressure. Since it might be harmful for country with low income level and high inequality to reduce CO_2 emission then lessening the emission reduction burden for those countries is one way to fulfill the idea of equity in emission reduction commitment. All these related results are presented in Table 3 (see Appendix).

Finally, the results summarized in Table 4 consistently find that with account of income inequality the total amount of emission reduction of current 32 Annex B countries and 32 plus 4 other potential targeted countries are all higher than their counterpart scenarios with concern of income level only. The global efficient emission reduction will be reached with such a relative comprehensive reduction distribution principals in hand. Furthermore, with concern of income inequity and income level, the total emission reductions for different scenarios can thus be calculated. If current emission reductions are all committed then the total emission reduction is 195,559,800 metric tons from 32 Annex B countries. If this amount is treated as the minimum emission reduction goal then accounting for income inequality by managing high and low income countries differently and reallocating the emission reduction percentage accordingly CO_2 emission will be reduced more and up to 229,355,845 metric tons. This signifies that with equity concern, the emission reduction array will reduce global total emission more efficiently. It is not surprised to find more total emission with additional 4 new joining countries. The emission reduction increases to 265,276,245.4 metric tons and this level is higher than the total emission reduction 244,414,476 metric tons for these 36 countries with concern of income level only.

While look closely for the change of the total emission reduction from different levels of income group countries, it is found that low income group countries with concern of income inequality and income level reduce 40.70% emission reduction burden as compared to current status for concern income level only. The emission reduction burden is switched to high income countries by increasing 22.76% as they currently commit to. This obligation will not be released until other 4 new joining countries have brought into the emission reduction array.

Table 4. Total amount of emission reduction under various reallocation scenarios[a]

32[b] countries' total current emission reduction if all committed with concern of income level only	195,559,800.0
Total emission reduction of low income countries	16,890,260.0
Total emission reduction of high income countries	178,669,540.0
32 countries' total emission reduction with concern of income inequality and income level	229,355,845.0
Total emission reduction of low income countries	10,015,150.0
Total emission reduction of high income countries	219,340,695.0
36[c] countries' total emission reduction with concern of income level only	244,414,476.0
Total emission reduction of low income countries	60,556,012.0
Total emission reduction of high income countries	183,858,464.0
36 countries' total emission reduction with concern of income inequality and income level	265,276,245.4
Total emission reduction of low income countries	50,819,071.3
Total emission reduction of high income countries	214,457,174.1

Note: [a]The unit is in metric ton. [b]Thirty-two countries are mainly the current Annex B countries in Kyoto Protocol except Croatia, Iceland, Liechtenstein, Monaco, New Zealand and Switzerland. [c]Thirty-six countries include 32 countries in note b and China, India, South Korea, and Taiwan.

Conclusions

This study utilizes data across 52 countries in 14 years and the results indicate that the influence of income inequality to CO_2 emission varies by different economic development stages. Moreover, the relationship between income inequality and CO_2 emission is not monotonically related but influenced by income levels. With the prominent influence of income inequality on CO_2 emission, the emission reduction percentages for countries currently in Annex B of the Kyoto Protocol and 4 other potential emission reduction targeted countries, China, India, South Korea, and Taiwan are reallocated while income inequality is accounted for.

The results show that high income and high inequality countries are urge to implement emission reduction properly by assigning higher weight of reduction percentages. Similarly, low income and low inequality countries confront analogous situations as high income and high inequality countries. As such, a relative efficient CO_2 emission reduction will be generated globally. That is, with such reallocation, total CO_2 emission reduction reduces 17.28% more than that if all 32 Annex B countries meet their current reduction commitments. Likewise, the total CO_2 emission reduction increases another 8.54% when China, India, South Korea, and Taiwan are included among the potential commitment countries array.

Since the emission reduction burden of high income countries is released while income inequality and income level are accounted for with 36 countries in the bargaining table and the emission reduction obligation for low income countries are increased relatively mild when both income inequality and income level of the countries are used to justify reduction allocation. The inclusion of equity in the emission reduction reallocation percentage does not only yield the advantage of a global efficient emission reduction occurrence. More importantly, it induces higher incentive for countries with different income levels for further negotiation.

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Appendix

Table 2. Reallocation results of CO_2 emission reduction for 32 Annex B countries of Kyoto Protocol

Country	Gini	Emission amount in 1990[a]	Original reduction percentage	Total original reduction amount[a]	+ (β - α) for high income countries			- (β - α) for low income countries		
					Reduction percentage after reallocation	Total reduction amount after reallocation[a]	Reduction percentage after reallocation	Total reduction amount after reallocation[a]	Reduction percentage after reallocation	Total reduction amount after reallocation[a]
High income group										
Australia	30.32	74,299,000	-8%	-5,943,920	-8.21%	-6,099,947.9	-156,027.9	-	-	-
Austria	25.26	15,749,000	8%	1,259,920	6.20%	976,438.0	-283,482.0	-	-	-
Belgium	29.34	27,459,000	8%	2,196,720	7.40%	2,031,966.0	-164,754.0	-	-	-
Canada	29.29	113,488,000	6%	6,809,280	5.33%	6,048,910.4	-760,369.6	-	-	-
Denmark	34.49	13,580,000	8%	1,086,400	8.54%	1,159,732.0	73,332.0	-	-	-
Finland	22.98	13,980,000	8%	1,118,400	5.40%	754,920.0	-363,480.0	-	-	-
France	29.30	98,919,000	8%	7,913,520	7.42%	7,339,789.8	-573,730.2	-	-	-
Germany	26.61	267,615,000	8%	21,409,200	6.56%	17,555,544.0	-3,853,656.0	-	-	-
Greece	34.29	19,712,000	8%	1,576,960	10.77%	2,122,982.4	546,022.4	-	-	-
Ireland	32.13	8,357,000	8%	668,560	8.48%	708,673.6	40,113.6	-	-	-
Italy	33.73	106,339,000	8%	8,507,120	8.69%	9,240,859.1	733,739.1	-	-	-
Japan	31.56	292,212,000	6%	17,532,720	5.73%	16,743,747.6	-788,972.4	-	-	-
Luxembourg	27.55	2,701,000	8%	216,080	7.25%	195,822.5	-20,257.5	-	-	-
Netherlands	25.46	38,125,000	8%	3,050,000	6.30%	2,401,875.0	-648,125.0	-	-	-
Norway	27.27	9,633,000	-1%	-96,330	-2.33%	-224,448.9	-128,118.9	-	-	-
Portugal	37.07	11,552,000	8%	924,160	11.82%	1,365,446.4	441,286.4	-	-	-
Spain	32.75	57,814,000	8%	4,625,120	9.22%	5,330,450.8	705,330.8	-	-	-
Sweden	24.57	13,498,000	8%	1,079,840	5.81%	784,233.8	-295,606.2	-	-	-
Slovenia	25.14	3,361,000	8%	268,880	8.36%	280,979.6	12,099.6	-	-	-
United Kingdom	33.76	155,375,000	8%	12,430,000	8.85%	13,750,687.5	1,320,687.5	-	-	-
United States	44.99	1,314,813,000	7%	92,036,910	10.41%	136,872,033.3	44,835,123.3	-	-	-
Total		2,658,581,000	138%	178,669,540	138.00%	219,340,695.0	40,671,155.0	-	-	-
Low income group										
Bulgaria	34.82	20,562,000	8%	1,644,960	-	-	-	7.71%	1,585,330.2	-59,629.8
Czech	26.19	36,948,000	8%	2,955,840	-	-	-	8.76%	3,236,644.8	280,804.8
Estonia	38.53	6,787,000	8%	542,960	-	-	-	7.38%	500,880.6	-42,079.4
Hungary	24.51	16,406,000	6%	984,360	-	-	-	6.92%	1,135,295.2	150,935.2
Latvia	33.13	3,474,000	8%	277,920	-	-	-	7.93%	275,488.2	-2,431.8
Lithuania	32.64	5,829,000	8%	466,320	-	-	-	7.96%	463,988.4	-2,331.6
Poland	32.14	94,865,000	6%	5,691,900	-	-	-	6.00%	5,691,900.0	0.0

Table 2 (cont.). Reallocation results of CO_2 emission reduction for 32 Annex B countries of Kyoto Protocol

Country	Gini	Emission amount in 1990[a]	Original reduction percentage	Total original reduction amount[a]	+ (β - α) for high income countries			- (β - α) for low income countries		
					Reduction percentage after reallocation	Total reduction amount after reallocation[a]	Reduction percentage after reallocation	Total reduction amount after reallocation[a]	Reduction percentage after reallocation	Total reduction amount after reallocation[a]
High income group										
Poland	32.14	94,865,000	6%	5,691,900	-	-	-	6.00%	5,691,900.0	0.0
Russian Federation	43.24	541,492,000	0%	0	-	-	-	-1.18%	-6,389,605.6	-6,389,605.6
Slovak Republic	25.46	11,752,000	8%	940,160	-	-	-	8.79%	1,033,000.8	92,840.8
Ukraine	37.37	163,760,000	0%	0	-	-	-	-0.65%	-1,064,440.0	-1,064,440.0
Total	34.82	944,198,000	68%	16,890,260	-	-	-	68.00%	10,015,150.0	-6,875,110.0

Note: [a] Unit is in metric ton.

Table 3. CO_2 emission reduction percentage reallocation including India, China, South Korea and Taiwan

Country	Gini	Emission amount in 1990[a]	Original reduction percentage	Total original reduction amount[a]	+ (β - α) for high income countries			- (β - α) for low income countries		
					Reduction percentage after reallocation	Total reduction amount after reallocation[a]	Reduction percentage after reallocation	Total reduction amount after reallocation[b]	Reduction percentage after reallocation	Total reduction amount after reallocation[b]
High income group										
Australia	30.32	74,299,000	-8.0%	-5,943,920	-8.33%	-6,189,106.7	-245,186.7	-	-	-
Austria	25.26	15,749,000	8.0%	1,259,920	6.50%	1,023,685.0	-236,235.0	-	-	-
Belgium	29.34	27,459,000	8.0%	2,196,720	7.39%	2,029,220.1	-167,499.9	-	-	-
Canada	29.29	113,488,000	6.0%	6,809,280	5.36%	6,082,956.8	-726,323.2	-	-	-
Denmark	34.49	13,580,000	8.0%	1,086,400	8.37%	1,136,646.0	50,246.0	-	-	-
Finland	22.98	13,980,000	8.0%	1,118,400	5.96%	833,208.0	-285,192.0	-	-	-
France	29.30	98,919,000	8.0%	7,913,520	7.41%	7,329,897.9	-583,622.1	-	-	-
Germany	26.61	267,615,000	8.0%	21,409,200	6.78%	18,144,297.0	-3,264,903.0	-	-	-
Greece	34.29	19,712,000	8.0%	1,576,960	9.72%	1,916,006.4	339,046.4	-	-	-
Ireland	32.13	8,357,000	8.0%	668,560	8.16%	681,931.2	13,371.2	-	-	-
Italy	33.73	106,339,000	8.0%	8,507,120	8.36%	8,889,940.4	382,820.4	-	-	-
Japan	31.56	292,212,000	6.0%	17,532,720	5.78%	16,889,853.6	-642,866.4	-	-	-
Luxembourg	27.55	2,701,000	8.0%	216,080	7.58%	204,735.8	-11,344.2	-	-	-
Netherlands	25.46	38,125,000	8.0%	3,050,000	6.57%	2,504,812.5	-545,187.5	-	-	-
Norway	27.27	9,633,000	-1.0%	-96,330	-1.96%	-188,806.8	-92,476.8	-	-	-
Portugal	37.07	11,552,000	8.0%	924,160	10.49%	1,211,804.8	287,644.8	-	-	-
Spain	32.75	57,814,000	8.0%	4,625,120	8.65%	5,000,911.0	375,791.0	-	-	-
Sweden	24.57	13,498,000	8.0%	1,079,840	6.30%	850,374.0	-229,466.0	-	-	-

Table 3 (cont.). CO_2 emission reduction percentage reallocation including India, China, South Korea and Taiwan

Country	Gini	Emission amount in 1990[a]	Original reduction percentage	Total original reduction amount[a]	+ (β - α) for high income countries			- (β - α) for low income countries		
					Reduction percen-tage after reallocation	Total reduction amount after reallocation[a]	Reduction percen-tage after reallocation	Total reduction amount after reallocation[b]	Reduction percen-tage after reallocation	Total reduction amount after reallocation[b]
High income group										
Slovenia	25.14	3,361,000	8.0%	268,880	7.87%	264,510.7	-4,369.3	-	-	-
United Kingdom	33.76	155,375,000	8.0%	12,430,000	8.46%	13,144,725.0	714,725.0	-	-	-
United States	44.99	1,314,813,000	7.0%	92,036,910	9.57%	125,827,604.1	33,790,694.1	-	-	-
South Korea	34.79	65,824,000	5.2%	3,422,848	7.24%	4,765,657.6	1,342,809.6	-	-	-
Taiwan	32.05	33,963,000	5.2%	1,766,076	6.19%	2,102,309.7	336,233.7	-	-	-
Total		2,758,368,000	148.4%	183,858,464	148.40%	214,457,174.1	30,598,710.1	-	-	-
Low income group										
Bulgaria	34.82	20,562,000	8.0%	1,644,960	-	-	-	7.84%	1,612,060.8	-32,899.2
Czech	26.19	36,948,000	8.0%	2,955,840	-	-	-	8.69%	3,210,781.2	254,941.2
Estonia	38.53	6,787,000	8.0%	542,960	-	-	-	7.56%	513,097.2	-29,862.8
Hungary	24.51	16,406,000	6.0%	984,360	-	-	-	6.83%	1,120,529.8	136,169.8
Latvia	33.13	3,474,000	8.0%	277,920	-	-	-	8.01%	278,267.4	347.4
Lithuania	32.64	5,829,000	8.0%	466,320	-	-	-	8.04%	468,651.6	2,331.6
Poland	32.14	94,865,000	6.0%	5,691,900	-	-	-	6.08%	5,767,792.0	75,892.0
Romania	28.51	42,323,000	8.0%	3,385,840	-	-	-	8.39%	3,550,899.7	165,059.7
Russian Federation	43.24	541,492,000	0.0%	0	-	-	-	-0.90%	-4,873,428.0	-4,873,428.0
Slovak Republic	25.46	11,752,000	8.0%	940,160	-	-	-	8.73%	1,025,949.6	85,789.6
Ukraine	37.37	163,760,000	0.0%	0	-	-	-	-0.46%	-753,296.0	-753,296.0
India	33.11	185,016,000	5.2%	9,620,832	-	-	-	5.10%	9,435,816.0	-185,016.0
China	39.77	654,710,000	5.2%	34,044,920	-	-	-	4.50%	29,461,950.0	-4,582,970.0
Total		1,783,924,000	78.4%	60,556,012	-	-	-	78.40%	50,819,071.3	-9,736,940.7

Note: [b] Unit is in metric ton.