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ORIGINAL PAPER

Assessment of equity principles for international climate policy based on an integrated assessment model

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Abstract

Defining an internationally equitable distribution of the burdens of reducing greenhouse gases has been one of core concerns for as long as climate policies have been debated. This paper suggests the specific formulae and indicators for four equity principles for international climate policy including the ability to pay, egalitarianism, grandfathering, and historical responsibility. We introduce the carbon trading scheme into the integrated assessment model to assess and compare the global climate policies which are based on the four principles. To be specific, the regional emission caps are determined by the four equity principles, and all regions are allowed to buy and sell permits. Results show that none of the four equity principles creates a burden sharing arrangement that completely equalizes the benefits of each nation. To be specific, grandfathering is more beneficial to developed countries, while historical responsibility benefits developing countries more. From the global perspective, the global cumulative output of the grandfathering is 8% higher than that of the historical responsibility. In addition, international cooperation on climate change mitigation is necessary, because if individual nations undertake policies which are in their national self-interests, global cumulative CO_2 emission will be over two times as much as that in cooperative scenarios.

Keywords Equity · Emission permits · Carbon trading · Grandfathering · Historical responsibility · Integrated assessment model

1 Introduction

There is wide consensus that current climate change and other global environment problems have been mainly caused by human activity since the First Industrial Revolution (IPCC 2013; Mi et al. 2014). Great network externalities exist in tackling climate change as it is a global issue; countries have little incentive to reduce emissions if other countries do not take measures to mitigate climate change. So global cooperation is necessary to reduce greenhouse gas (GHG) emissions (Jiang et al. 2017; Loulou et al. 2009; Mi et al. 2017b). However, one of the most difficult and complex issues in negotiating international cooperation is how to allocate the GHG emission reduction burdens among countries (Cao et al. 2016; Wei et al. 2015). This is the question of equity in mitigating climate change.

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The problem of equity in mitigating climate change could be interpreted at three different levels: equity principles, burden sharing formulae or rules, and criteria or indicators (Ringius et al. 2002). Following equity principles means establishing overarching general justice and fairness principles, which can be operationalized by linking them to formulae and rules. Burden sharing formulae and rules are specific operational approaches given input from criteria or indicators (Ringius et al. 1998).

In the past two decades, researchers and stakeholders have proposed various equity principles from different perspectives. The widely discussed equity principles include the ability to pay (Jacoby et al. 1998; Mattoo and Subramanian 2012), egalitarianism (Baer et al. 2000; Wicke 2004), grandfathering (Böhringer and Lange 2005; Kalkuhl and Brecha 2013), historical responsibility (Wei et al. 2012; Yang and Sirianni 2010), polluter pays (Kemfert and Tol 2002; Lange et al. 2007), Pareto rule (DeCanio and Fremstad 2013), and market justice (Metz 2000; Xu et al. 2016).

However, most distribution schemes based on these equity principles are not efficient. Gaps usually exist between the allocation schemes and the actual demand for GHG emission permits. The supplies of permits in some areas cannot satisfy their production needs, while those in other areas are higher than their actual needs. For instance, the permits' share of most developed countries will sharply shrink when historical responsibilities are taken into account. Some countries' future permits are even negative (Wei et al. 2014). This allocation plan is obviously inefficient.

Carbon trading scheme (i.e., cap and trade) is one of the methods to improve the efficiency of distribution schemes (Carbone et al. 2009; Mi et al. 2016). Under this mechanism, the regional caps on emissions are determined by the equity principles, and all regions are allowed to buy and sell permits. Participants who have sufficient permits or the capacity to reduce emissions comparatively cheaply will sell excess permits. Conversely, participants who lack permits or have higher reduction cost will buy permits (Cong and Wei 2010, 2012). In this way, total emissions will exactly equal the number of permits.

Up to now, no universal consensus exists on the best definition of international equity for mitigating climate change. The main purpose of this paper is to analyze the socioeconomic impacts of equity principles for international climate policy including the ability to pay, egalitarianism, grandfathering, and historical responsibility.

2 Literature review

Defining an internationally equitable distribution of the burdens of reducing greenhouse gases has been a core concern as long as climate policies have been debated. Since the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol were set forward, many equity principles have been proposed to allocate the burdens of mitigating climate change from different perspectives. Some literature has summarized the various equity principles which have been proposed. Rose (1992) discussed ten international equity principles. The principles were used to allocate carbon entitlements to eight major countries and world regions. Both static reference bases and dynamic reference bases taking into account cumulative emissions were employed. Cazorla and Toman (2001) reviewed twelve alternative equity principles that had been advanced for defining common but differentiated responsibilities. They concluded that no single principle could be expected to provide satisfactory resolution of this issue. However, approaches that involved adjusting responsibilities over time on the basis of more than one criterion were more likely to be accepted in the international negotiation. Wei et al. (2013) selected eleven proposals for an agreement on future climate policy that were presently prevailing over the world. For each proposal, based on the principle of a common but differentiated responsibility, they also conducted analysis on the background and main design methods, compared each mechanism employed in the proposals, discussed the matter of "Equity and Justice" that had become one of the most controversial issues in climate debates, and assessed the potential impact on both developed and developing countries.

Using one or more equity principles, some literature has introduced specific formulae and indicators to generate the allocation results of GHG abatement burden or emission permits. Rose et al. (1998) provided an analysis of nine equity principles, and calculated the global GHG emission permits allocation. They presented a nonlinear programming model capable of simulating these equity principles, and assessed their net costs of mitigation. Ringius et al. (1998) examined three specific burden sharing rules and presented cost calculations on the burden sharing rules. Results showed that none of them created a burden sharing arrangement that completely equalized the national income losses as percentage of gross domestic product (GDP) across the Organization for Economic Cooperation and Development (OECD), but burden sharing rules could be useful tools and provide some of the guiding framework for climate policy negotiations. Yi et al. (2011) selected per capita GDP, accumulated fossil fuel-related CO_2 emissions and energy consumption per unit of industrial added value as indicators for emission reduction capacity, responsibility, and potential, respectively. Based on the three indicators, they generated four burden sharing formulae, and allocated the abatement burden across the provinces in China. Wei et al. (2014) allocated the carbon emission accounts through 137 countries and regions on the basis of per capita cumulative emissions. They argued that the CO_2 emission permits share of most developed countries would decrease dramatically if historical responsibilities are taken into consideration. They also presented a method to achieve a common but differentiated responsibility shift, in the hope of providing the framework for carbon permits distribution to be deliberated in the forthcoming climate change program.

Climate change impacts the social system as well as the natural system (Mi et al. 2017a, 2018). In order to assess the impacts of climate policies more accurately, climate change integrated assessment model (IAM) which usually includes a climate module and an economic module has been introduced (Böhringer et al. 2009; Tol 2002, 2009). Nordhaus (1991) combined an economic system and a climate system into a model framework to assess climate policies, which marked the beginning of the climate change IAM model. The advantages of IAMs were accepted by the Intergovernmental Panel on Climate Change (IPCC), and many IAMs have made significant contributions to IPCC Assessment Report (IPCC 2007, 2014). The IAMs can be divided into three broad categories by their methodologies: optimization model, computable general equilibrium (CGE) model, and simulation model. The overview of IAM can be found in Dowlatabadi and Morgan (1993), Stanton et al. (2009), and Wei et al. (2015).

3 Methodology

First of all, the four principles are translated into operational formulae and indicators for distributing CO_2 emission permits. Second, the global total CO_2 emission permits from 2000 to 2100 are determined from historical emissions and the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) (IPCC 2013). Third, based on the four rules, the total emission permits are distributed through six regions: the USA, Japan, the European Union (EU), China, the former Union of Soviet Socialist Republics

(USSR), and the rest of the world (ROW). Ultimately, the permits allocation results are simulated by the RICE model (Nordhaus and Boyer 2000; Nordhaus and Yang 1996; Yang 2008).

3.1 Roles of burden sharing

The problem of equity in international climate policy can be interpreted at three different levels: equity principles, burden sharing formulae, and indicators. The ability to pay, egalitarianism, grandfathering, and historical responsibility are four equity principles, and they need to be translated into operational rules to allocate the CO_2 emission permits by specific computing formulae and indicators. It should be noted that most of the equity principles would yield more than one possible distribution rule, depending on what formulae are chosen and how the key parameters are set.

The ability to pay is to equalize abatement costs across countries relative to economic circumstances. Per capita GDP or gross national product (GNP) is usually used as the indicator of emission reduction capacity. Therefore, the CO_2 emission permits are inversely correlated with per capita GDP under this principle. One operational computing formula is (Germain and Van Steenberghe 2003)

$$e_i = H \times \frac{L_i \times \left(\frac{Y_i}{L_i}\right)^{-\lambda}}{\sum_j \left[L_j \times \left(\frac{Y_j}{L_j}\right)^{-\lambda}\right]}, \tag{1}$$

where e_i is the CO_2 emission permit of region i, H is global total emission permit, L_i is the population of region i in the base year, Y_i is the GDP of region i in the base year, and λ is an exogenous parameter ($0 < \lambda < 1$). In this paper, λ is set to 0.5 (Germain and Van Steenberghe 2003).

Egalitarianism means that all people have equal rights to use atmospheric resources (Baer et al. 2000). So the emission permits are allocated in proportion to population in the base year,

$$e_i = H \times \frac{L_i}{L_w}, \tag{2}$$

where L_w is the global population in the base year.

Grandfathering means that current emission levels determine future emission rights (Demailly and Quirion 2006). In other words, the more one country emits CO_2 emissions in the base year, the more it gets the emission permits in the future. So the emission permits are allocated in proportion to emissions in the base year,

$$e_i = H \times \frac{E_i}{E_w}, \tag{3}$$

where E_i is the CO_2 emission of region i in the base year, and E_w is the global CO_2 emission in the base year.

Historical responsibility refers to the principle that historical emissions should be taken into consideration (Pan and Chen 2010). The countries that emit more CO_2 emission in the past should take on more responsibilities in the future. It is assumed that the emission permits should be allocated in proportion to population in every single year (Wei et al. 2014),

$$e_i = H \times \frac{L_i}{L_w} + \sum_{t=t_0}^{2000} E_w^t \times \frac{L_i^t}{L_w^t} - \sum_{t=t_0}^{2000} E_i^t, \tag{4}$$

where t_0 is the beginning year of historical responsibilities, E_w^t is the global CO_2 emission in year t, E_i^t is the CO_2 emission of region i in the year t, L_w^t is the global population in year t, and L_i^t is the population of region i in the year t. Table 1 summarizes the four alternative equity principles for international climate policy, with computing formulae of how each could be translated into rules for allocating CO_2 permits.

In this paper, 2000 is chosen as the base year to allocate the global CO_2 emission permits from 2000 to 2100 (Sørensen 2008). It is widely accepted that greenhouse gas (GHG) emitted from fossil energy is the main cause of human-induced climate change. Fossil energy has been used on a large scale since the First Industrial Revolution which began from about 1760. Thus, humanity's historical responsibilities for causing climate change began from 1760. However, historical data of carbon emission before 1900 are not available. Therefore, the historical responsibilities are calculated from 1900 (Pan and Chen 2010).

3.2 The integrated assessment model with carbon trading scheme

The model used in this paper is the Regional Integrated model of Climate and the Economy (RICE) model which was developed originally by Nordhaus and Yang (1996). It is a simple, forward-looking IAM of the world climate and economy. It has played a leading role in the integrated assessment of climate change over the last 10 years. The RICE is the most flexible and transparent of the popular and influential IAMs. Therefore, it is not surprising that RICE has found a large number of external users and a wide range of applications (Wei et al. 2015). We introduce the carbon trading scheme (cap and trade) into the RICE. To be specific, the regional cap of emissions is determined by the equity principles (formula 1–4), and all regions are free to buy and sell permits in order to obtain the lowest cost for themselves.

The basic structure of the RICE consists of four parts: (1) objective function; (2) regional economic growth module; (3) carbon emission, concentration, and temperature change module (or "carbon cycle" module); (4) economic-climate linkage. The model can be formulated either as a social planner's optimal control problem (cooperative scenario) or as an open-loop differential game with regions as players (non-cooperative scenario) (Yang 2008). Figure 1 shows the framework of the RICE model. The four allocation schemes of global carbon emission permits are all simulated under the cooperative scenario. The non-cooperative scenario is also calculated for comparison.

In the social planner's optimal control problem, the objective function is a weighted sum of present values of the intertemporal regional utility functions,

$$\text{Max} \quad W = \sum_{i=1}^{m} U_i = \sum_{i=1}^{m} \int_0^T \varphi_i L_i(t) Log(C_i(t)/L_i(t))\, e^{-\delta t} \mathrm{d}t, \tag{5}$$

$$\sum_{i=1}^{m} \varphi_i = m,\ 0 < \delta < 1, \tag{6}$$

Table 1 Four equity principles for climate policy and computing formulae

Equity principle	Interpretation	Operational rule	Computing formula
Ability to pay	Equalize abatement costs across countries relative to economic circumstances	Permits are inversely correlated with per capita GDP	$e_i = H \times \frac{L_i \times \left(\frac{Y_i}{L_i}\right)^{-\lambda}}{\sum_j \left[L_j \times \left(\frac{Y_j}{L_j}\right)^{-\lambda}\right]}$
Egalitarianism	All people have equal rights to use atmospheric resources	Allocate permits in proportion to population	$e_i = H \times \frac{L_i}{L_w}$
Grandfathering	Current emission levels determine the future emission rights	Allocate permits in proportion to emissions	$e_i = H \times \frac{E_i}{E_w}$
Historical responsibility	Allocate abatement burden according to historical responsibilities	Allocate permits according to historical emissions	$e_i = H \times \frac{L_i}{L_w} + \sum_{t=t_0}^{2000} E_w^t \times \frac{L_i^t}{L_w^t} - \sum_{t=t_0}^{2000} E_i^t$

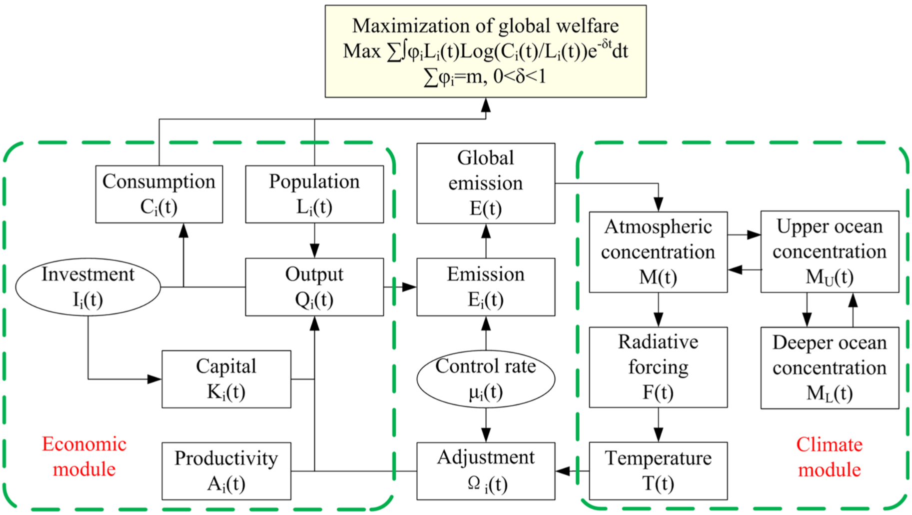

Fig. 1 The framework of RICE model as a social planner's optimal control problem. The variables in the ellipses (i.e., investment and control rate) are control variables

where W is the global social welfare, U_i is the present value of intertemporal utility of region i, φ_i is the social welfare weight for region i, $L_i(t)$ is the labor (population) of region i, $C_i(t)$ is the consumption of region i, δ is the pure rate of time preference, m is the number of regions, $i = 1, 2, \ldots, m$.

In contrast, the objective function of the open-loop differential game is a single region's present value of its intertemporal utility function,

$$\text{Max} \quad \int_0^T L_i(t)\text{Log}(C_i(t)/L_i(t))\, e^{-\delta t}\text{d}t, \quad 0<\delta<1, \quad i=1,2,\ldots,m. \tag{7}$$

In the economic module, the output is obtained by a Cobb–Douglas aggregate production function. The production function uses labor and capital as the two primary factors. The function is enhanced by an exogenous and time-variant total factor productivity.

$$Q_i(t) = A_i(t)K_i(t)^{\gamma}L_i(t)^{1-\gamma}, \tag{8}$$

where, $Q_i(t)$ is the output of region i, $A_i(t)$ is the total factor productivity of region i, $K_i(t)$ is the capital stock level of region i, γ is the output elasticities of capital. It can be seen that the production function has constant returns to scale.

Because climate change may have effects on output, and carbon trading is allowed, the output $Q_i(t)$ is adjusted by

$$Y_i(t) = \Omega_i(t)Q_i(t) + G_i(t), \tag{9}$$

where $Y_i(t)$ is the adjusted production function of region i, $\Omega_i(t)$ is the climate factor of region i, $G_i(t)$ is the gain by carbon trading of region i. In the carbon trading system, all regions are free to buy and sell permits,

$$\sum_t \left(\frac{G_i(t)}{p(t)} + E_i(t)\right) = e_i, \tag{10}$$

where $p(t)$ is the carbon price, $E_i(t)$ is the emission of region i, e_i is the emission permit of region i. If $G_i(t)$ is positive, it means that region i sells permits to other regions at time t; otherwise, the region i buys permits. It is supposed that one region needs to pay immediately when buying the permits. Therefore, the sum of gains by carbon trading is zero each year,

$$\sum_i G_i(t) = 0. \tag{11}$$

The output can be used for consumption and investment, so there are the trade-offs between current consumption and investment within the budget of "real GDP" (not gross output $Q_i(t)$),

$$C_i(t) = Y_i(t) - I_i(t), \tag{12}$$

where $C_i(t)$ is the consumption of region i, $I_i(t)$ is the investment of region i (the control variable). The capital formation process is

$$\dot{K}_i(t) = I_i(t) - \delta_K K_i(t), \tag{13}$$

where δ_K is the depreciation rate of the capital stock, $0<\delta_K<1$.

The climate module is a simplified box model of the carbon cycle. The approach originated with Schneider and Thompson (1981) and was recalibrated by Nordhaus based on other carbon cycle models (Nordhaus and Boyer 2000). The module captures dynamic processes of interactions among lower and upper oceans, and atmospheric carbon concentrations, radiative forcing of GHGs, and deep-ocean and atmospheric temperature changes. The module is a process of differential systems. The driver of this module is the aggregate GHG emission $E(t)$ (the sum of regional GHG emissions $E_i(t)$) generated from the economic module. $E(t)$ affects GHG concentrations in three layers (atmosphere, upper ocean, and deeper ocean); GHG concentrations affect radiative forcing; radiative forcing leads to temperature change. The feedback from this module to the economic module is the atmospheric temperature increase $T_1(t)$. In sum, higher $E(t)$ leads to higher $T_1(t)$ through this dynamic module.

The economic and climate module are linked through (9), (14), and (15) in the model,

$$E_i(t) = (1 - \mu_i(t))\sigma_i(t)Q_i(t), \tag{14}$$

$$\Omega_i(t) = \frac{1 - b_{1,i}\mu_i(t)^{b_{2,i}}}{1 + a_{1,i}T_1(t)^{a_{2,i}}}, \tag{15}$$

where $E_i(t)$ is the GHG emission of region i, $\mu_i(t)$ is the GHG emission control rate of region i (control variable), $0 \leq \mu_i(t) \leq 1$, $\sigma_i(t)$ is the exogenous GHG emission/output ratio of region i, $T_1(t)$ is the atmospheric temperature increase, $a_{1,i}$, $a_{2,i}$, $b_{1,i}$, and $b_{2,i}$ are exogenous damage parameters of region i. For each region, GHG emissions are declining proportionally with respect to GDP production, when there are no emission control efforts. This assumption is consistent with historical observations that long-run energy intensity (thus carbon intensity) gradually reduces worldwide due to technological changes (Canadell et al. 2007; Schmalensee et al. 1998; Sun 1998). In the model, a region can reduce GHG emissions from the no-control baseline by choosing the GHG control rate $\mu_i(t)$. When $\mu_i(t) = 0.1$, it means 10 percent GHG emission reduction from the baseline. GHG reduction which mitigates climate change can reduce climate damage, but it is also costly. Such trade-offs are reflected by (15), which is the ratio of the GHG mitigation cost function and the climate damage function. Either temperature ($T_1(t)$) increases or control cost ($\mu_i(t)$) increases, the lower the value of $\Omega_i(t)$.

4 Data sources

The historical data of GDP[1] and population from 1900 to 2000 are derived from the World Bank Open Database (World Bank 2014). The CO_2 emission data are gotten from the Carbon Dioxide Information Analysis Center (CDIAC) (Boden et al. 2014) and the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5) (IPCC 2013).

The total allowable CO_2 emission on a global scale in the future is both a complicated and controversial issue. The IPCC AR5 provides four Representative Concentration Pathways (RCPs) as a basis for the climate predictions and projections.[2] The RCPs are scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases and aerosols and chemically active gases, as well as land use/land cover (Moss et al. 2010). We chose an intermediate stabilization scenario named RCP4.5, in which the cumulative fossil fuel emissions from 2012 to 2100 are 780 gigatonnes of carbon (GtC). The historical emissions from 2000 to 2011 are 96.75 GtC according to CDIAC. Therefore, global total CO_2 emission permits (2000–2100) are 876.75 GtC.

[1] GDP is calculated using 2000 official exchange rates.

[2] The four Representative Concentration Pathways (RCPs) are RCP2.6, RCP4.5, RCP6.0, and RCP8.5. See Chapters 11 to 14 of IPCC AR5 for a more detailed description.

5 Results and analysis

According to the four equity principles, the global emission permits (2000–2100) are allocated through six regions: the USA, Japan, the EU, China, former USSR, and ROW. Then the allocation of permits is simulated by the RICE model to assess the global CO_2 emission pathways and the socioeconomic impacts. It should be noted that six regions are divided into developed countries and developing countries: the USA, Japan, the EU, and the former USSR are developed countries, while China and the ROW are developing countries.[3]

5.1 Allocation of CO_2 emission permits

Global emission permits, which are 876.75 GtC, are allocated by formulae (1)–(4). It can be seen from Fig. 2 that the allocation results under the four equity principles differ greatly.

The grandfathering principle is more beneficial to developed countries. The USA, Japan, the EU, and the former USSR all gain the most emission permits under grandfathering. The total emission permits of developed countries under the grandfathering principle are 462.92 GtC, which is more than ten times as many as that under the historical responsibility principle. This is mainly because grandfathering allocates the emission permits in proportion to emissions in the base year.

On the contrary, the historical responsibility principle is more beneficial to developing countries. Under historical responsibility, the developing countries gain 832.33 GtC emission permits, which is about twice as many as that under grandfathering. Developed countries, which emitted 192.53 GtC from 1900 to 1999, have more historical responsibilities than developing countries whose CO_2 emissions were 72.80 GtC during the same period. Therefore, developing countries receive more benefits if historical responsibilities are taken into account.

Moreover, it should be noted that the USA's emission permits are negative (− 22.63 GtC) under the historical responsibility principle. In other words, the USA had consumed 200 years' worth of permits from 1900 to 1999. The CO_2 emissions of the USA from 1900 to 1999 are 77.26 GtC which accounts for 29.12% of global emission permits during the same period.

5.2 Global CO_2 emission pathways

The four allocation schemes are simulated by the RICE model. For each scenario, the optimal CO_2 emission pathway is calculated with the objective of maximizing global welfare (see Fig. 3). In addition, the RICE model provides the non-cooperative scenario under which individual nations undertake policies that are in their national self-interests and ignore the spillovers of their actions on the other nations.

It can be seen from Fig. 3 that global CO_2 emissions in the non-cooperative scenario are much more than those under the four cooperative scenarios. Under the non-cooperative scenario, the global cumulative CO_2 emissions from 2000 to 2100 are 2003.85 GtC, which is 2.29 times as many as that of the cooperative scenarios. There are enormous externalities

[3] The rest of the world (ROW) contains some developed countries, but the most of ROW are developing countries. Therefore, the ROW is seen as developing countries.

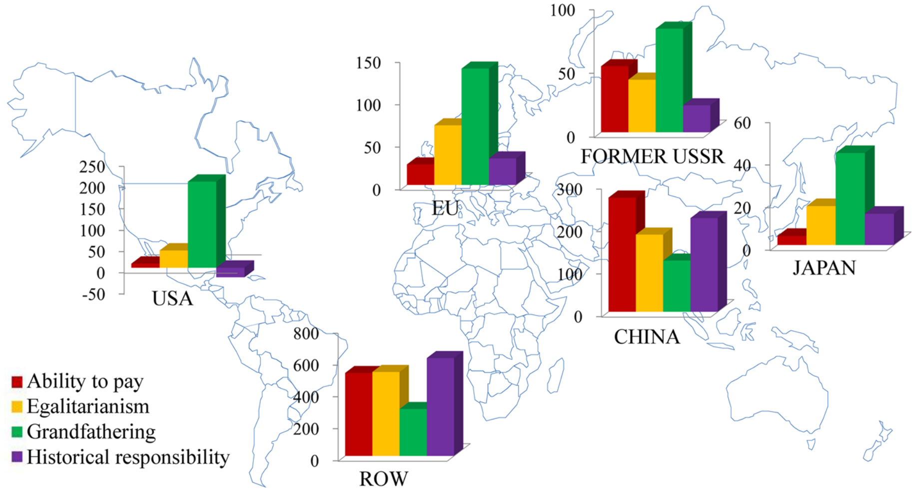

Fig. 2 The allocation of CO_2 emission permits from 2000 to 2100. The unit of emission permits is GtC. It is a schematic map and does NOT proscribe the definite boundaries

in coping with climate change, so countries have little incentive to reduce emissions if other countries do not take measures to mitigate climate change.

From the global perspective, grandfathering pays more attention to the welfare of future generations. The CO_2 emissions peak in approximately 2050 under the scenarios of the ability to pay, egalitarianism, and historical responsibility. However, grandfathering allocates more emission permits to the latter half of the century.

5.3 Socioeconomic impacts

Global CO_2 emission permits' allocation under the four equity principles differs greatly. In this section, we take GDP, consumption, and capital stock as the indicators of national benefits to analyze the socioeconomic impacts of the four distribution schemes.

First of all, the global cumulative GDP from 2000 to 2100 under grandfathering is the highest (see Fig. 4). From the global perspective, the cumulative GDP under grandfathering is 8.24% higher than that under the historical responsibility principle. It is known that carbon intensity (CO_2 emission per GDP) of developed counties is much lower than that of developing countries. So given the same CO_2 emission permits, developed countries can produce more output. In the four distribution schemes, developed countries get the most emission permits under the grandfathering. Therefore, the global cumulative GDP of the grandfathering is the highest. However, developing countries share more abatement burdens under grandfathering. The cumulative GDP of developing countries under grandfathering is 18.90% lower than that under historical responsibility.

Second, the global cumulative consumption from 2000 to 2100 under grandfathering is the lowest (see Fig. 5). From the global perspective, the cumulative consumption under the ability to pay, egalitarianism, and historical responsibility principles are almost the same, and all are higher than that of under grandfathering.

Third, the global capital stock under grandfathering is always the highest in every single year from 2000 to 2100 (see Fig. 6). On the contrary, the global capital stock under

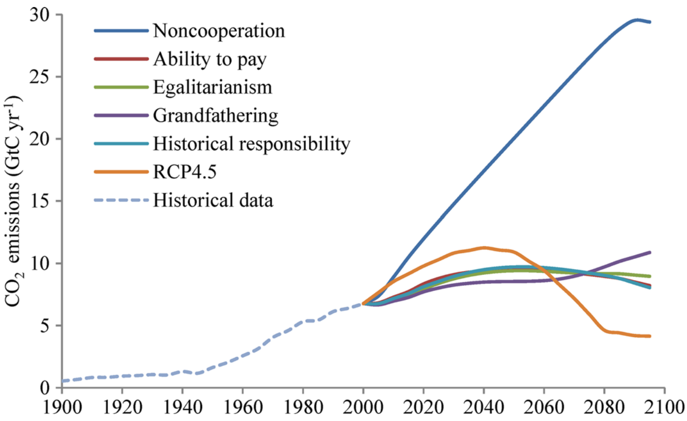

Fig. 3 The global CO_2 emission pathways under different scenarios

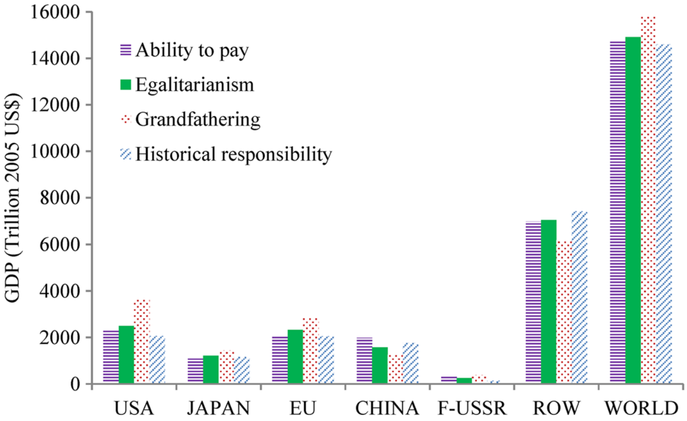

Fig. 4 The cumulative GDP of different regions from 2000 to 2100

historical responsibility is the lowest. In 2100, the global capital stock under grandfathering is more than twice as much as that under historical responsibility.

6 Conclusions and policy implications

This paper introduces the specific formulae and indicators for four equity principles for international climate policy: ability to pay, egalitarianism, grandfathering, and historical responsibility. Based on the four principles, the global CO_2 emission permits from 2000 to 2100 are allocated through six regions: the USA, Japan, the European Union, China, the former Union of Soviet Socialist Republics, and the rest of the world. Then, we introduce the carbon trading scheme into the RICE model to simulate the four distribution schemes to assess and compare their socioeconomic impacts.

1. None of the four equity principles creates a burden sharing arrangement that completely equalizes the national benefits. To be specific, grandfathering is more beneficial to developed countries, while the historical responsibility principle benefits

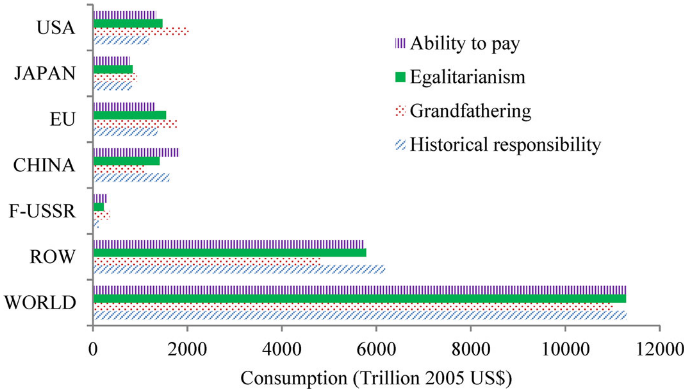

Fig. 5 The cumulative consumption of different regions from 2000 to 2100

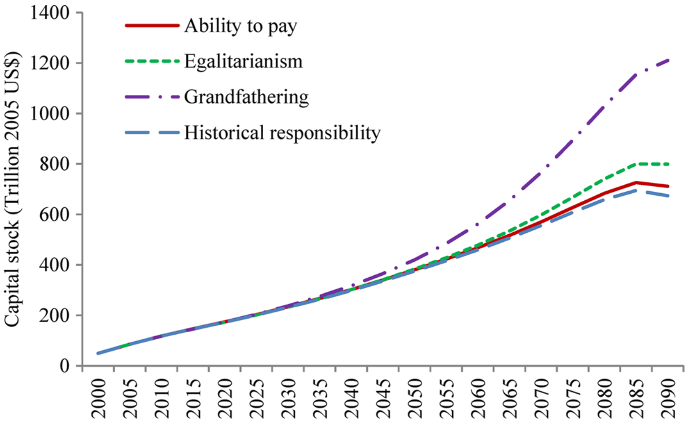

Fig. 6 The global capital stock from 2000 to 2100

developing countries more. As for the CO_2 emission permits' allocation, developed countries gain the most permits under grandfathering, while developing countries gain the most permits under the historical responsibility principle. As for the socioeconomic impacts, developed countries' GDP, consumption, and capital stock are all the highest under grandfathering. On the contrary, developing countries gain the highest GDP and consumption when the historical responsibilities are taken into account.

2. It is necessary for all nations to cooperate together to mitigate climate change. If individual nations undertake policies which are in their national self-interests, the global CO_2 emission will be 2.29 times as much as that of cooperative scenarios.
3. The global cumulative GDP and capital stock under grandfathering are both the highest among the four equity principles. The global cumulative GDP under grandfathering is 8.24% higher than that of the historical responsibility, and the global capital stock under grandfathering is always the highest in every single year from 2000 to 2100. Moreover, from the global perspective, grandfathering pays more

attention to the welfare of future generations, because it allocates more emission permits to the latter half of the centenary.

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