Chapter 2
MRICES

2.1 Introduction

Since the 1990s, climate change policy simulation has been developed in two categories, the Integrated Assessment Models (IAM) and the Computable General Equilibrium (CGE) model. The climate change IAM is recognized as a broad, integrated model that analyzes scientific and socioeconomic aspects of climate change primarily for the purpose of assessing policy options for climate change control (Kelly and Kolstad 1999). IAM research includes the DICE and RICE models established by Nordhaus (1991) and Nordhaus and Boyer (2000), respectively; the FOUND model established by Link and Tol (2004); the MERGE model established by Manne et al. (1995) and Manne and Richels (2004); and the TIAM and ETSAP-TIAM models established by McGill (Loulou and Labriet 2007; Loulou 2008). Models based on the IAM in China have also been developed by Jiang and Hu (2002), Chen et al. (2004), Wang et al. (2002, 2004), among others. For reference, CGE-based models of climate policy simulation have been developed by Dixon et al. (1982), the OECD (1992), Burniaux et al. (1992), Mckibbin and Wilcoxen (1993), Nijkamp et al. (2005) and Bussolo et al. (2008).

In this chapter, we focused on an IAM-based model. The most representative IAM-based models of climate change are the DICE (Dynamic Integrated model of Climate and the Economy) and RICE (Regional Integrated model for Climate and the Economy) model. In 1990, Nordhaus first presented the DICE model (Nordhaus 1990), which contains no regional disaggregation, so that policymakers cannot implement region-specific policies. As an extension of DICE, RICE is a multiregional model that divides the world into six regions: the United States, China, the European Union, Japan, the former Soviet Union and the rest of the world (Nordhaus and Yang 1996). In 1999, a new version of RICE separated the world into eight groups: the United States, other high income countries, OECD Europe, Russia and Eastern Europe, middle income countries, lower-middle income countries and low income countries (Nordhaus and Boyer 2000). The more detailed a

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region is modeled, the more accurate the results are produced for a specified regional policy simulation. There are many multiregional models of climate policy, including the 25-region WIAGEM model (Kemfert 2005), the 6-region ETC-RICE model (Buonanno et al. 2003) and the 32-country POLES model, among others. The DICE and RICE models as a paradigm for climate change modeling have been undergoing continuous improvements; however, there are still rooms for further modifications. In this study, we introduced multilateral GDP spillovers into the IAM.

Although spillovers in climate change modeling have been studied for a long time, most researches have focused on technological spillovers (Rao et al. 2006; Golombek and Hoel 2003) and R&D spillovers (Buonanno et al. 2003) that would affect mitigation technology. However, modern countries have become much closer through trade and cooperation than they have been at any time in the past. GDP growth causes international spillovers; i.e., GDP growth in one country may have a positive or negative influence on other countries. For example, Luh and Shih (2006) discovered that spillover contributed to GDP growth between Japan and Korea but dampened Taiwan's GDP growth between 1978 and 1992. In particular, the 2008 global financial crisis, which was initially triggered by the bursting of the U.S. housing bubble, spread to all regions of the world, resulting in dire consequences for global trade, investment and growth. With the 2008 financial crisis, India's 2008–09 GDP growth decreased to approximately 7.1% from 9% annual growth before (Jha 2009). Weeks (2009) reported that the 2008 global financial crisis caused a fall in export earnings in Sierra Leone of approximately 15% in 2009 compared to 2008. Liu (2009) found that the impact of the global financial crisis on China's economy was sizeable; a 1% decline in economic growth in the US, the EU and Japan is likely to result in a 0.73% decline in growth in China. International economic interactions have become so strong and complex that no country can remove itself from the global economy. Therefore, climate policies enacted in one nation will have an indirect economic influence on other countries via trade.

GDP spillovers in climate change can no longer be neglected; however, the number of researchers studying modeling of this issue is still small. Grubb et al. (2002) have divided the international spillover from GHG emissions reductions on developing countries into three aspects: spillovers from economic substitution, spillovers from diffuse technological changes and political effects on developing countries from the mitigation actions of industrialized countries. GDP spillovers from the mitigation actions of developed countries will significantly contribute to global emissions reduction (Grubb et al. 2002). Wang et al. (2010) combined the Mundell-Fleming model with a climate change model to examine the GDP spillover from climate policies between the United States and China. A crucial conclusion of Wang et al. (2010) was that one country should consider the emissions mitigation policies of other countries when enacting its own. Thus, the inclusion of GDP spillovers in models against climate change is essential; otherwise, assessments on climate policy are biased.

This study established the MRICES (Multi-regional integrated model of climate and economy with GDP spillovers) model, which integrates multilateral GDP spillovers into climate change modeling. Furthermore, several global mitigation strategies were assessed using the MRICES model to determine whether these strategies are climatically effective and economically efficient.

2.2 Model Description

MRICES is a dynamic model that combines climate and economic factors. It divides the world into six regions: the US, Japan, the European Union (EU), China, the former Soviet Union (FSU) and the rest of the world (ROW). Each region has its own economic system and shares the global climate system. The economic system describes the economic activities of each region, and global emissions can be determined on the basis of these activities. Global emissions will result in a temperature change in the global climate system, and the increase in temperature will then affect the economic system. The dynamic interaction between climate and economic systems is illustrated in Fig. 2.1.

2.2.1 Economic System

Based on the partitioning of the world in MRICES, the global economic system is also composed of six interdependent subsystems with identical modeling structures. The specific equations in the economic system are described below.

$$Y_{i,t} = A^*_{i,t} K^{\alpha}_{i,t} L^{1-\alpha}_{i,t} \tag{2.1}$$

Equation (2.1) describes the regional output based on the Cobb-Douglas production function from capital, $K_{i,t}$ and labor, $L_{i,t}$; i represents the number of the region, and t represents the simulation time, $A^*_{i,t}$ is a measure of exogenous productivity, and α and $1-\alpha$ represent the elasticity of capital and labor, respectively. Changes in $A^*_{i,t}$ depend on the exogenous productivity, $A_{i,t}$, according to Eq. (2.2), which has been

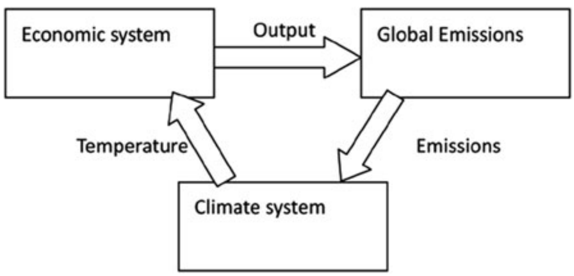

Fig. 2.1 The relationship between economic and climate systems in MRICES

adopted by Nordhaus and Yang (1996), Pizer (1999) and Eyckmans and Tulkens (2003), and $A_{i,t}$ grows with the annual decline in growth rate shown in Eq. (2.3).

$$A^*_{i,t} = \left(\frac{1 - b_{i,1}\mu_{i,p}}{1 + (D_0/9)T^2_{i,t}} \right) A_{i,t} \tag{2.2}$$

$$\ln(A_{i,t}) = \ln(A_{i,t-1}) + \gamma_{i,a} \exp(-\delta_{i,a} t) + \sigma_a \tag{2.3}$$

In these equations, $\mu_{i,p}$ describes the emissions reduction rate from production control, $b_{i,1}$ is the parameter for emissions control, D_0 is the fractional loss in aggregate GDP from a 3 °C temperature increase, $T_{i,t}$ is the average surface temperature (in °C) relative to that before industrialization, $\gamma_{i,a}$ is the initial growth rate of productivity, $\delta_{i,a}$ describes the annual decline in growth rate, and σ_a is the standard error for random shock.

In Eq. (2.1), the capital stock $K_{i,t}$ grows as

$$K_{i,t+1} + K_{i,t}(\delta_{i,K}) + I_{i,t}, \tag{2.4}$$

where $\delta_{i,K}$ is the capital depreciation rate, and $I_{i,t}$ denotes the investment during the corresponding period derived from

$$I_{i,t} = \eta_i Y_{\mathrm{i},t} - \eta_{i,I} - I^{(cs)}_{i,t} - I^{(f)}_{i,t} + I^{(n)}_{i,t} - M^{(f)}_{i,t} + M^{(n)}_{i,t}), \tag{2.5}$$

where η_i is the annual rate of investment, $\eta_{i,I}$ is the proportion of climate protection deducted from investment as a policy parameter, $I^{(cs)}_{i,t}$ is the investment in increasing carbon sinks, $I^{(f)}_{i,t}$ and $I^{(n)}_{i,t}$ are the investments in fossil and non-fossil fuel energy sources, respectively, and $M^{(f)}_{i,t}$ and $M^{(n)}_{i,t}$ are the maintenance costs of fossil and non-fossil fuel energy sources, respectively. The sum of the terms in parentheses in Eq. (2.5) is considered to be the cost of handling climate change. To determine the annual investment, household consumption can be expressed as

$$C_{i,t} = Y_{i,t} - I_{i,t} - (1 - \eta_{i,I})(I^{(cs)}_{i,t} - I^{(f)}_{i,t} + I^{(n)}_{i,t} - M^{(f)}_{i,t} + M^{(n)}_{i,t}). \tag{2.6}$$

Equations (2.5) and (2.6) implicitly indicate that two emissions reduction actions, carbon sinks and energy substitution need financial support. The source of emissions reduction costs is different from that of van der Zwaan et al. (2002), in which the cost for handling climate change is defined as part of output. In our model, the cost of emissions reduction is partially derived from consumption, with a rate of $(1 - \eta_{i,I})$ and partially derived from investment, with a rate $\eta_{i,I}$. As a result, actions against climate change influence the utility of each region, as shown by the Ramsey function:

$$U_i(n) = \sum_{t=1}^{n} (1+\rho_i)^{-t} L_{i,t}^{(s)} \frac{(C_{i,t}/L_{i,t}^{(s)})^{1-\tau_i}}{1-\tau_i}, \tag{2.7}$$

where $U_i(n)$ is the utility when take a control policy in region i, and ρ, τ describes the discount rate and risk aversion to consumption per capita across time.

2.2.2 Emissions Mitigation

As previously mentioned, the link between the economic and climate systems is the global emissions level, which is the sum of the six regional emissions. It can be determined from the following equations:

$$E_{i,t}^{(c)} = \sigma_{i,t}(1-\mu_{i,c})Y_{i,t}\left(\frac{A_{i,t}}{A_{i,t}^*}\right) \tag{2.8}$$

and

$$E_t = \sum_{\mathrm{i}=1}^{6} E_{i,t}^{(c)}, \tag{2.9}$$

where $E_{i,t}$ is the regional emissions level, $\mu_{i,c}$ is the integrated reduction rate, E_t is the global emissions level, and $\sigma_{i,t}$ is an exogenous trend in emissions per output, which declines as

$$\ln(\sigma_{i,t}) = \ln(\sigma_{i,t-1}) - \gamma_{i,\sigma}\exp(-\delta_{i,\sigma}t) \tag{2.10}$$

where $\gamma_{i,\sigma}$ is the initial growth rate for the emissions trend, and $\delta_{i,\sigma}$ is the annual decline in the growth rate.

For emission mitigation, there are three reduction measures considered in MRICES model, including production controlling, energy substitution and carbon sinks increasing. The gross emission reduction rate $\mu_{i,c}$ is presented in Eq. (2.11).

$$\mu_{i,c} = \mu_{i,p} + \mu_{i,s} + \mu_{i,d} \tag{2.11}$$

where $\mu_{i,p}$, $\mu_{i,s}$, $\mu_{i,d}$ denote reduction rate of production controlling, carbon sinks increasing and energy substitution respectively. The cost for carbon sink increasing can be written as

$$I_{i,t}^{(cs)} = C_i^{(s)} \mu_{i,s} \sigma_{i,t} Y_{i,t} \left(\frac{A_{i,t}}{A_{i,t}^*} \right) \tag{2.12}$$

where $C_i^{(s)}$ is cost for increasing carbon sinks in a ton of emission reduction, $\sigma_{i,t}$ is the carbon intensity representing the trend of emission/output, which changes according to Eq. (2.10).

In order to calculate the use of fossil fuel and non-fossil fuel annually under the policy of energy substitution, the total energy consumption in each period has to be figured out as

$$En_{i,t} = \varsigma_{i,t} Y_{i,t} \left(\frac{A_{i,t}}{A_{i,t}^*} \right) \tag{2.13}$$

where $\varsigma_{i,t}$ is the exogenous trend for energy intensity per output which grows according to function (2.13).

$$\ln(\varsigma_{i,t}) = \ln(\varsigma_{i,t-1}) + \gamma_{i,\sigma} \exp(-\delta_{i,a} t) \tag{2.14}$$

Therefore, the amount of non-fossil fuel is proportionally related to gross energy consumption and the emission reduction rate of energy substitution.

$$N_{i,t} = F_{i,t} / \lambda_{i,,FN} (1 - \mu_{i,d}) \tag{2.15}$$

where $\lambda_{i,FN}$ represents the proportion of fossil fuel in total energy consumption. On the other hand, if there is no policy of energy substitution, Eq. (2.15) can be replaced as

$$N_{i,t}^* = F_{i,t}^* / \lambda_{i,FN} \tag{2.16}$$

where $N_{i,t}^*$, $F_{i,t}^*$ is the non-fossil and fossil consumption respectively if no energy substitution policy is applied. Since consumptions of fossil and non-fossil fuel make up the total energy use, we can further get the consumption of fossil fuel with Eq. (2.17), no matter energy substitution policy is implemented or not.

$$En_{i,t} = F_{i,t} + N_{i,t} \tag{2.17}$$

Thus, the consumption difference of fossil fuel or non-fossil fuel between with and without energy substitution policy is caught as

$$\Delta N_{i,t} = N_{i,t} - N_{i,t}^* \tag{2.18}$$

$$\Delta F_{i,t} = F_{i,t}^* - F_{i,t} \tag{2.19}$$

Ground on the energy consumption in each period, we introduce the learning-by-doing mechanism which is proposed by van der Zwaan et al. (2002) into our model.

$$I_{i,t-1}^{(n)} = g(X_{i,t}^{(n)})a_{i,N}\Delta N_{i,t} \tag{2.20}$$

$$M_{i,t}^{(n)} = g(X_{i,t}^{(n)})b_{i,N}\Delta N_{i,t} \tag{2.21}$$

$$I_{i,t-1}^{(f)} = g(X_{i,t}^{(f)})a_{i,F}\Delta F_{i,t} \tag{2.22}$$

$$M_{i,t}^{(f)} = g(X_{i,t}^{(f)})b_{i,F}\Delta F_{i,t} \tag{2.23}$$

Equations (2.20)–(2.23) describe learning by doing for the investment and maintenance cost of non-fossil and fossil energy consumption respectively, where $I_{i,t}^{(n)}$ and $I_{i,t}^{(f)}$ are investment while $M_{i,t}^{(n)}$ and $M_{i,t}^{(f)}$ are for maintenance, function g(.) reflects technological change from accumulative consumption, $a_{i,F}, b_{i,F}$ is the capital intensity and maintenance intensity for fossil energy respectively, $a_{i,N}, b_{i,N}$, $a_{i,F}, b_{i,F}$ is the capital intensity and maintenance intensity for non-fossil energy respectively, $X_{i,t}^{(f)}$, $X_{i,t}^{(n)}$ is the accumulative consumption of fossil and non-fossil energy respectively. By van der Zwaan et al. (2002), we give

$$g(x) = g_0 x^{\upsilon-1} \tag{2.24}$$

$$l_r = 1 - 2^{\upsilon-1} \tag{2.25}$$

in which the value of the exponent $\upsilon - 1$ is the basis of the process of learning-by-doing and derives from Eq. (2.25) related to learning rate l_r.

2.2.3 GDP Spillovers

The mechanism of GDP spillovers in MRICES model is similar to Wang et al. (2010), but the bilateral structure is extended so that a multilateral GDP spillover can be investigated in climate change model. Figure 2.2 illustrates how the modeling of GDP spillovers is coupled with other parts of the model. Generally speaking, GDP of different countries work on each other, so that the emission of each country is impacted, resulting a global temperature raise which will make a feed back to productivity of each country. Thus a circular interaction from GDP spillovers to productivity via temperature raise is constructed. For data inaccessibility we modeled the GDP spillovers among China, the United States, Japan and Europe Union. The GDP influence from other regions can be expressed in residual.

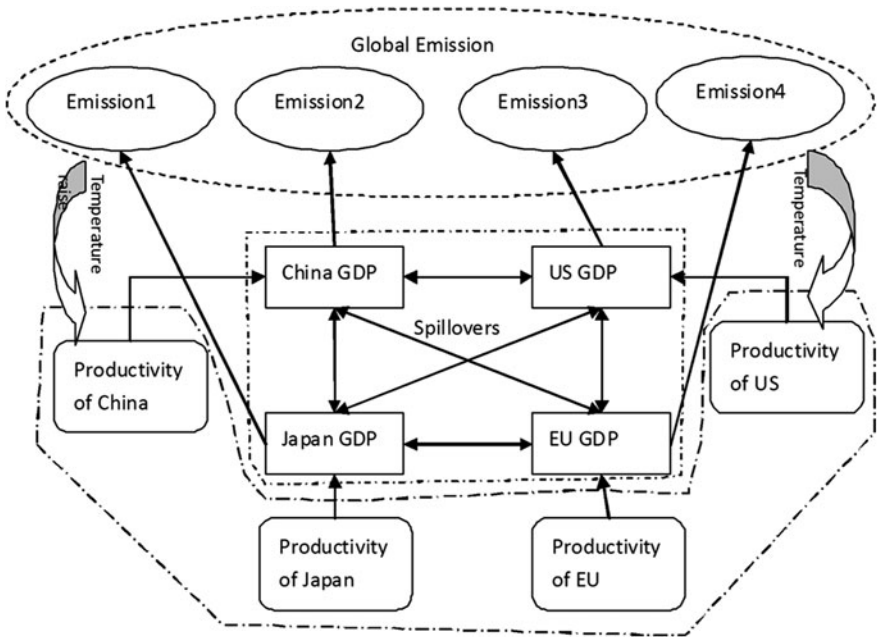

Fig. 2.2 Coupling of GDP spillover with Climate sub-system and Economic sub-system

Based on Mundell-Fleming model and Wang et al. (2010), the change of GDP is decomposed into impact from monetary policies, political policies and the GDP fluctuation of other countries, expressed in Eqs. (2.26)–(2.29).

$$\Delta q^c = v_1^c \Delta\lambda^{ca} - v_2^c \Delta(i^c - p^c_{+1} + p^c) + v_3^c \Delta q^a + v_4^c \Delta q^j + v_5^c \Delta q^e \tag{2.26}$$

$$\Delta q^a = v_1^a \Delta\lambda^{ea} - v_2^a \Delta(i^a - p^a_{+1} + p^a) + v_3^a \Delta q^c + v_4^a \Delta q^j + v_5^a \Delta q^e \tag{2.27}$$

$$\Delta q^j = v_1^j \Delta\lambda^{ja} - v_2^j \Delta(i^j - p^j_{+1} + p^j) + v_3^j \Delta q^c + v_4^j \Delta q^a + v_5^j \Delta q^e \tag{2.28}$$

$$\Delta q^e = v_1^e \Delta\lambda^{ae} - v_2^e \Delta(i^e - p^e_{+1} + p^e) + v_3^e \Delta q^c + v_4^e \Delta q^a + v_5^e \Delta q^j \tag{2.29}$$

In expression (2.26)–(2.29), superscript *c*, *a*, *j*, *e* presents variables of China, the US, Japan and EU respectively. Δq represents the deviation from the base simulation result. $\Delta\lambda$ presents the deviation from the base of real exchange. Δi presents the deviation from the base of interest rate.

Based on Eqs. (2.26)–(2.29), we can get the GDP spillover between countries (regions), shown as Eqs. (2.30)–(2.33).

$$\ln Y^c - \ln Y^c_{-1} = v^c_3(\ln Y^a - \ln Y^a_{-1}) + v^c_4(\ln Y^j - \ln Y^j_{-1}) + v^c_5(\ln Y^e - \ln Y^e_{-1}) \quad (2.30)$$

$$\ln Y^a - \ln Y^a_{-1} = v^a_3(\ln Y^c - \ln Y^c_{-1}) + v^a_4(\ln Y^j - \ln Y^j_{-1}) + v^a_5(\ln Y^e - \ln Y^e_{-1}) \quad (2.31)$$

$$\ln Y^j - \ln Y^j_{-1} = v^j_3(\ln Y^c - \ln Y^c_{-1}) + v^j_4(\ln Y^a - \ln Y^a_{-1}) + v^j_5(\ln Y^e - \ln Y^e_{-1}) \quad (2.32)$$

$$\ln Y^e - \ln Y^e_{-1} = v^e_3(\ln Y^c - \ln Y^c_{-1}) + v^e_4(\ln Y^a - \ln Y^a_{-1}) + v^e_5(\ln Y^j - \ln Y^j_{-1}) \quad (2.33)$$

In expression (2.30)–(2.33), Y^c, Y^a, Y^j and Y^e presents the GDP of China, the US, Japan and EU respectively by which the dynamic interaction between national economy is constructed with GDP spillover mechanism.

2.3 Parameter Estimation

With the model construction described above, the MRICES system was developed to simulate climate change mitigation strategies. Since some of the parameters in economic system are referenced from Eyckmans and Tulkens (2003), Nordhaus and Boyer (2000) and van der Zwaan et al. (2002), we just list the values in Appendix A.

What should be pointed out is that the descending of emission intensity from Nordhaus (1993) and Pizer (1999) is figured out on 1990s' data, however the current technological progress makes fleetly reduced emission intensity in recent years. In other words, the progress in emission intensity from Nordhaus (1993) and Pizer (1999) is underestimated for current condition. So that we estimate the current change of emission intensity based on input-output table of China and the US, which are representative for developing countries and developed countries respectively. Result indicates that the emission intensity decrease 5.3% annually in developing countries with 4.6% in developed countries. For convenience, the change of emission intensity from Nordhaus (1993) and Pizer (1999) is denoted as 'lower technological change' and the one we estimated is denoted as 'higher technological change' during the rest of the paper. We will consider each mitigation strategy under the two technological progress levels.

On the other hand, since the GDP spillover module is the new we integrate into the IAM, we determine the parameter estimation as well. Run with SPSS13.0, we get the value for GDP spillovers as Tables 2.1, 2.2, 2.3 and 2.4.

Table 2.1 Values for parameters in Eq. (2.30)[a]

Parameter	v_0^c	v_1^c	v_2^c	v_3^c	v_4^c	v_5^c	v_6^c
Value	0.004	0.067	−0.005	0.432	0.229	−1.533	1.805
Sig.	0.002	0.334	0.357	0.105	0.104	0.001	0.000

[a]Analyzed with SPSS 13.0; significance was set at the 5% level

Table 2.2 Values for parameters in Eq. (2.31)[a]

Parameter	v_0^a	v_1^a	v_2^a	v_3^a	v_4^a	v_5^a	v_6^a
Value	−0.01	−0.174	−0.271	−0.016	0.399	−0.027	0.259
Sig.	0.396	0.060	0.001	0.152	0.065	0.165	0.102

[a]Analyzed with SPSS 13.0; significance was set at the 5% level

Table 2.3 Values for the parameters in Eq. (2.32)[a]

Parameter	v_0^j	v_1^j	v_2^j	v_3^j	v_4^j	v_5^j	v_6^j
Value	0.042	−0.038	0.127	0.032	-0.082	1.011	0.154
Sig.	0.479	0.239	0.057	0.112	0.185	0.001	0.290

[a]Analyzed on SPSS 13.0; significance was set at the 5% level

Table 2.4 Values of the parameters in Eq. (2.33)[a]

Parameter	v_0^e	v_1^e	v_2^e	v_3^e	v_4^e	v_5^e	v_6^e
Value	−0.004	0.015	−0.194	0.00006	0.515	0.167	0.238
Sig.	0.102	0.436	0.000	0.746	0.000	0.053	0.014

[a]Analyzed on SPSS 13.0; significance was set at the 5% level

2.4 Assessment of Emissions Mitigation Strategies

Nowadays, a variety of mitigation strategies are being proposed (Stern 2008; BASIC 2006; Baer and Athanasiou 2008). But the quantitative influences from these strategies on national economy and global climate change are unclear, for which we can't discriminate which strategy is much better. Therefore, we assessed several mitigation strategies using our model from the perspective of effectiveness, equality and efficiency.

2.4.1 Egalitarian Allocation of Emissions Quotas

The egalitarian principle allocates emissions permits based on the population of each country. People in both developed and developing countries have equal rights to an emissions permit. However, a key problem with this principle is that industrialization occurred much earlier in developed countries than in developing countries. Tremendous carbon emissions levels have been observed since the Second Industrial Revolution due to industrialization in developed countries. As a result, North America and Europe have produced approximately 70% of the total amount of CO_2 emissions since 1850 due to energy production, whereas developing countries have accounted for less than 25% of these emissions (Stern 2006). In developing countries with extremely low historical levels of emissions, the current level of emissions is necessary to support their current level of industrialization. Thus, it would be unfair to assign emissions permits to developing and developed countries under the egalitarian principle without considering historical emissions levels.

To evaluate the control of global CO_2 concentrations to within 500 ppm by the year 2050, 1990 and 2005 were used as the starting point for historical emissions levels and the year for allocation, respectively. The mechanism for egalitarian allocation can be described by Eqs. (2.34) and (2.35).

$$P_i^{All} = pop_{i,2005} * \frac{P_w}{pop_{w,2005}} \tag{2.34}$$

$$P_i^R = P_i^{All} - P_i^H \tag{2.35}$$

Here, P_i^{All} represents the total number of emissions permits that nation i is assigned during the period from 1990 to 2050; $pop_{i,2005}$ and $pop_{w,2005}$ represent the populations of nation i and the world in 2005, respectively; P_w is the total number of emissions permits the entire world can use; P_i^R denotes the number of residual emissions permits of nation i from 2006 to 2050; and P_i^H is the level of historical emissions during the period from 1990 to 2005. The specific levels of historical emissions and residual emissions for several nations (regions) are shown in Fig. 2.3.

The business-as-usual (BAU) emissions level of each nation can be estimated based on MRICES, and the emissions gaps between BAU emissions demands and residual emissions quotas are shown in Table 2.5. Clearly, the emissions gap in the

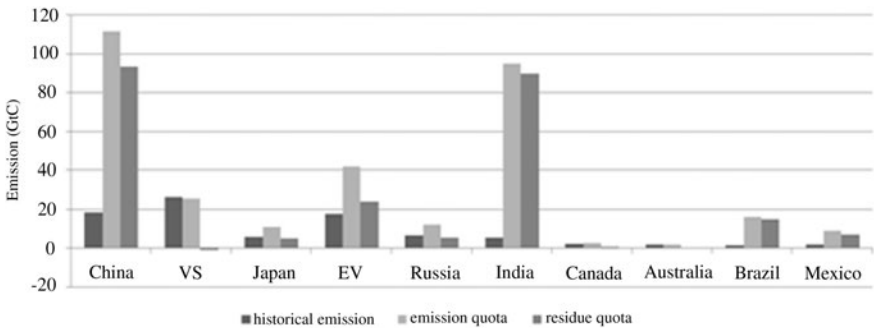

Fig. 2.3 The emissions quotas for each country (region) in the egalitarian strategy

Table 2.5 Emissions trading for each nation (region) in the egalitarianism strategy[a]

	China	US	Japan	EU	FSU	ROW
BAU emissions until 2050	95.93	81.77	16.95	53.08	44.20	164.31
Residual emissions quotas	93.39	−0.96	5.08	24.11	5.3	239
Emissions gaps	2.54	82.73	11.87	28.97	38.90	−74.68

[a]The year 1990 is used for a historical emissions starting point (units: GtC)

Table 2.6 Simulation results for the egalitarianism strategy

	Lower technological change	Higher technological change
	Loss of accumulated GDP by 2050	Loss of accumulated GDP by 2050
China	−0.013%	0.004%
US	−0.7%	−0.5%
Japan	−0.34%	−0.12%
EU	−0.33%	−0.019%
FSU	−2.8%	−1.9%
ROW	0.03%	0.016%
Temperature rise by 2050	1.48 °C	1.42 °C
Temperature rise by 2100	2.31 °C	2.02 °C
CO_2 concentration by 2050	426.7 ppm	414.6 ppm
CO_2 concentration by 2100	508.89 ppm	450.37 ppm
Change of world utility by 2050	−0.18%	−0.01%
Change of world utility by 2100	0.88%	1.55%

US is extremely large, at approximately 82.73 GtC, and the US must develop substantial emissions reduction measures or purchase emissions permits from other nations. In the case of China, the emissions demands during the period from 2008 to 2050 are almost equal to its residual emissions quotas, which imply that the emissions reduction burden for China will be relatively less than that of other developed nations if the egalitarian allocation strategy is instituted. In Table 2.5, it appears that the FSU must buy many emissions permits (Table 2.5), but this is not the case in actuality because there is ‘hot air’[1] in the FSU that can alleviate the pressure of emissions reduction.

To evaluate the influence of the egalitarianism strategy on global climate change, a policy simulation based on MRICES was developed. The results are summarized in Table 2.6, and the changes in CO_2 concentrations are depicted in Fig. 2.4.

[1]‘hot air’: when the baseline emissions are below their entitlements, the amounts of the abundant emissions rights are referred to as ‘hot air’.

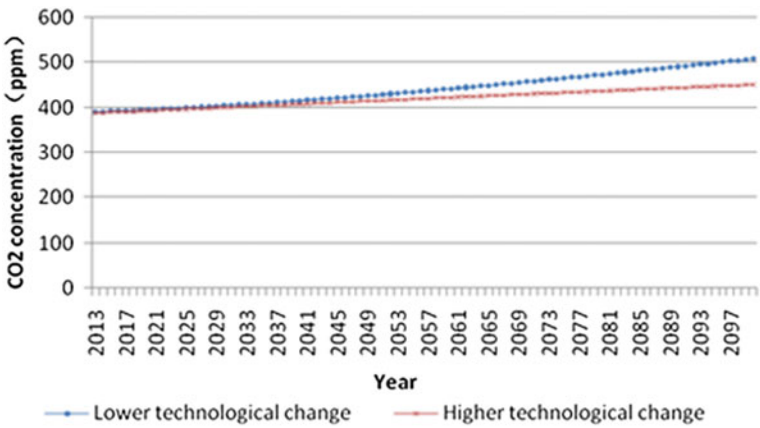

Fig. 2.4 Changes in CO_2 concentrations under the egalitarianism strategy, using 1990 as the baseline for historical emissions levels

With lower levels of technological change, the egalitarianism strategy can control the CO_2 concentration to within 500 ppm by 2050, but the temperature change by 2100 would surpass the target set by the EU. These results illustrate that a CO_2 concentration within 500 ppm is not consistent with the 2 °C target by 2100. The CO_2 concentration limit at 2050 must be further lessened, which means that countries must reduce emissions even more if this target is to be met by 2100. Notably, however, if the levels of technological change increase, both the 2050 and 2100 targets will be attained.

From the perspective of economic influence, the FSU will suffer from GDP loss more than other nations because the reduction rate in the FSU is relatively higher when the model does not consider the 'hot air', which leads to a stronger economic influence. Compared with the world accumulated utility by 2050 and 2100 under BAU scenario, it is found that the change of accumulated utility by 2050 is negative but positive by 2100 either with lower or higher technological change. So in the long-run egalitarian strategy is beneficial for utility improvement.

Thus, the egalitarianism strategy, using 1990 as the baseline for historical emissions levels, can achieve the 2050 target of controlling CO_2 concentration to within 500 ppm and the 2100 target of controlling the global temperature change to within 2 °C. Based upon the results of this strategy, developed nations must make a stronger commitment to activities that counteract the climate change caused by their tremendous historical levels of emissions. Due to the emissions gaps that developed nations face, these nations may need to purchase emissions rights instead of focusing on domestic emissions reduction measures to alleviate the average mitigation cost.

2.4.2 UNDP Strategy

In 2008, the UNDP proposed a mitigation strategy in which developed countries were required to reduce their emissions levels by 80% relative to their 1990 levels, and developing countries had to reduce their emissions levels by 20% relative to their 1990 emissions levels (UNDP 2008).

Using a MRICES policy simulation, we found that the global temperature will rise approximately 1.79 and 1.75 °C under lower and higher levels of technological change, respectively, under the UNDP strategy. This result indicates that the UNDP strategy would be effective for controlling global climate change. In particular, under higher levels of technological change, each country could attain its mitigation target with much lower reduction rates than those under lower levels of technological change.

With regard to the changes in global CO_2 concentrations, the trends under the two levels of technological change develop differently, as shown in Fig. 2.5. Specifically, under lower levels of technological change, the trend in CO_2 concentrations is U-shaped, which indicates that although the concentration would fall in the beginning of the mitigation period, it would then begin to increase after approximately 2045. Conversely, the trend in CO_2 concentrations under higher levels of technological change converges by the end of the century, which indicates that global emissions will be controlled at a certain level in the long-term. Thus, a higher level of technological change is distinctly better for accomplishing climate protection.

The accumulated GDP losses in each country resulting from reaching the targets described in the UNDP strategy are listed in Table 2.7. The GDP losses in developing countries are higher than those in developed countries, indicating that developing countries must invest more relative to their ability to pay. However, the

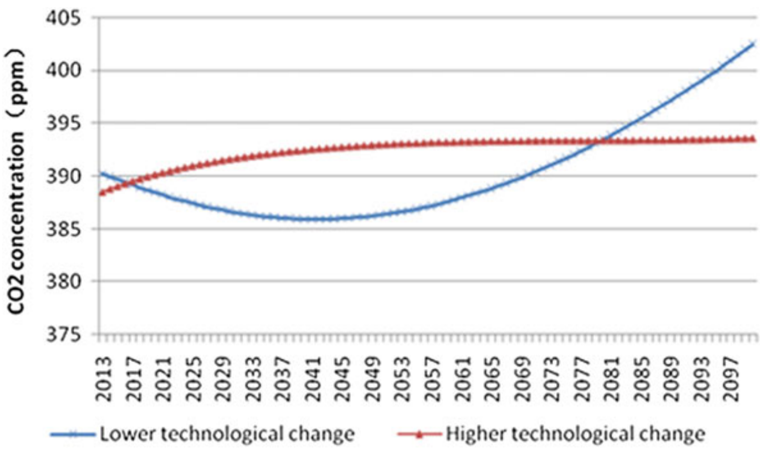

Fig. 2.5 Changes in CO_2 concentrations under the UNDP strategy

Table 2.7 Simulation results for the UNDP strategy

	Lower technological change	Higher technological change
	Loss of accumulated GDP by 2050	Loss of accumulated GDP by 2050
China	1.46%	0.52%
US	0.92%	0.46%
JAPAN	0.36%	0.17%
EU	0.38%	0.01%
FSU	1.79%	0.36%
ROW	0.96%	1.4%
Temperature rise by 2050	1.43 °C	1.48 °C
Temperature rise by 2100	1.79 °C	1.75 °C
CO_2 concentration by 2050	386.5 ppm	392.9 ppm
CO_2 concentration by 2100	402.9 ppm	393.5 ppm
Change of world utility by 2050	−0.72%	−0.44%
Change of world utility by 2100	−0.07%	0.26%

situation associated with GDP loss in developing countries becomes less severe when their emissions decline based on a higher level of technological change. Therefore, transferring advanced technologies from developed countries to developing countries can help to release the mitigation burden on developing countries.

Although the influence of emissions reduction on the economy is relatively tempered, this strategy is still far from appropriate as a basis for global action. The emissions per capita by 2050 varies among countries; the highest per capita level in the US is approximately 4.7TCO_2e, which is one-fold the world average, as shown in Fig. 2.6.

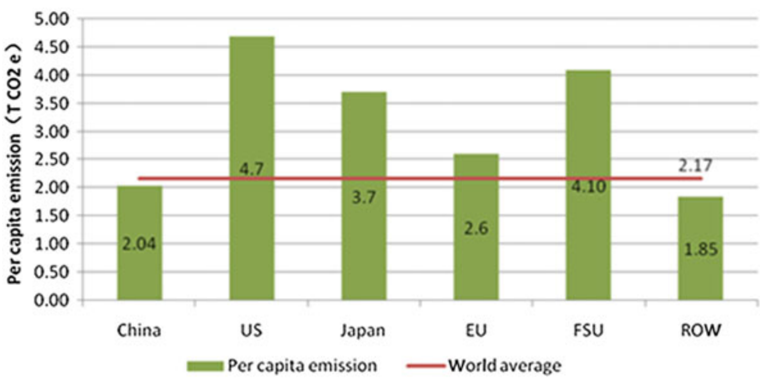

Fig. 2.6 Emissions per capita by 2050 under the UNDP strategy

Thus, the UNDP Strategy can address global climate change to a significant extent, but developing countries must absorb higher costs for mitigation and gain lower emissions per capita than developed countries, which will result in a new inequality in emissions rights and development rights throughout the world. The change of world utility by 2050 and 2100 is also undesirable when compared with that of egalitarian strategy, which means the world cost more for climate change. The key fault of the UNDP strategy is that developing countries are required to participate in emissions reduction simultaneously with developed countries. Developing countries cannot manage the implementation of emissions reduction measures and the elimination of poverty at the same time.

Based on our assessment, there should be differentiated obligations for developed and developing nations, with the objective of sustaining the equity rights of economic development. Therefore, two key issues should be emphasized when developing a global emissions mitigation strategy. Developed nations must assume more responsibility in global emissions reduction. Furthermore, developed nations must implement substantial emissions reduction measures earlier than developing nations so that developed nations will have time to achieve economic development and further alleviate the effects of climate change on the economies of developing nations.

2.4.3 Copenhagen Accord

Based on the Copenhagen Accord, Annex I parties should strengthen their emissions reduction measures, whereas non-Annex I parties should develop nationally appropriate mitigation actions. The mitigation action targets for 2020 proposed by the five countries (regions), which were modeled using MRICES, are listed in Table 2.8.

Because no strategy has been proposed for emissions reduction after 2020, we assume that each country will continue the mitigation actions listed in Table 2.8 until 2100 to explore the consequences on climate change. Based on a policy simulation using MRICES, the increase in global temperature was found to be

Table 2.8 Mitigation actions for 2020 in Copenhagen Accord

	Mitigation target	Base year	Base value	Target value
China	Reducing the emissions intensity per unit of GDP in 2020 by 40–45%	2005	7.99 t/10,000 $	4.39 t/10,000 $
US	Reducing emissions 17% by 2020	2005	1.57 GtC	1.30 GtC
EU	Reducing emissions 30% by 2020	1990	1.20 GtC	0.84 GtC
Japan	Reducing emissions 25% by 2020	1990	0.29 GtC	0.22 GtC
Russia	Reducing emissions 25% by 2020	1990	1.03 GtC	0.75 GtC

approximately 1.2 °C by 2020, 1.9 °C by 2050 and 2.8 °C by 2100. Clearly, this result exceeds the target to limit the rise in global temperature to within 2 °C by 2100. Therefore, much stronger mitigation actions must be taken after 2020; otherwise, combating climate change will become rather difficult if the temperature increases 1.9 °C by 2050.

From the perspective of emissions intensity changes, a relatively even reduction rate was revealed among the modeled countries. China exhibits a 45% reduction in emissions intensity from 2005 levels by 2020, and the US, the EU, Japan and the FSU exhibit 47%, 46%, 57% and 49% reductions in emissions intensity, respectively. However, emissions reduction is not easy for any country, and technological development is crucial for all countries; in particular, technological transfer from developed to developing countries is essential.

2.4.4 A Strategy to Achieve the 2 °C Target

On the basis of the "common but differentiated responsibilities" principle, developed countries are asked to develop more emissions reduction measures at an earlier time to address global climate change. Therefore, to achieve the 2 °C target by 2100, we propose that developed countries reduce emissions by 80% below 1990 levels by 2050, that the FSU reduce emissions by 50% below 1990 levels by 2050 and that China and the ROW reduce emissions by 28% and 20%, respectively, below 2005 levels. Policy simulations show that the strategy we proposed can maintain the temperature rise below 2 °C by the year 2100.

Using this strategy, we compared the decreases in carbon intensity of each country by 2050 and 2100, as shown in Fig. 2.7. China will exhibit an 89.9% reduction in carbon intensity by 2050 relative to 2005, which is close to that of developed countries, and the decrease in carbon intensity of the ROW will be reduced by 79.6% by 2050, which is relatively lower than those of other countries. However, the decrease in carbon intensity will be nearly equal among all countries

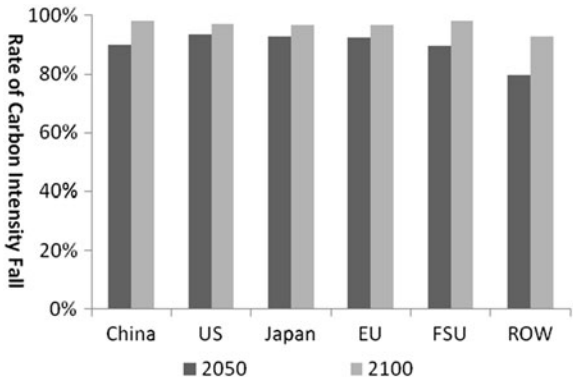

Fig. 2.7 Comparison of the declines in carbon intensity by 2050 and 2100

by 2100, and the decreases in China and the FSU will even surpass those of developed countries. Thus, based on the changes in carbon intensity, the emissions reduction efforts in developed and developing countries are equal.

2.5 Conclusions and Discussion

As we approach the post-Kyoto era, there are an increasing number of mitigation strategies to address climate change. This study sought to develop an assessment strategy for these strategies based on the objectives of effectiveness, equality and efficiency. For this purpose, a climate policy model with GDP spillovers was presented. Based on an extension of the Mundell-Fleming model, we simulated the economic interactions among China, the US, the EU and Japan with a GDP spillover mechanism. Consequently, emissions reduction measures developed in one country will not only influence that country's economy but also the economies of the other countries via GDP spillover.

Based on assessments on the egalitarian allocation strategy, the UNDP strategy and the Copenhagen Accord using MRICES, it is found that the egalitarian strategy is helpful for developed countries to get more emission permits.

On account of equality, efficiency and effectiveness, there are several principles which we have pay more attentions to when making global emission reduction strategies. Firstly, the principle of common but differentiated responsibility must be insisted, so that developed countries can contribute more in emission reduction. Based on this principle, cutting 80% relative to 1990 levels by 2050 in developed countries can be considered as the precondition for emission reduction in developing countries. Secondly, it's not practical to take the same year as the baseline for emission reduction in both developed and developing countries, otherwise the reduction target will be too challenging for developing countries. Alternatively, 1990 and 2005 can be base years for developed and developing countries respectively. Thirdly, promoting advanced technologies from developed countries to developing countries is one of the ways to combat global climate change more effectively and efficiently.

Appendix A

See Appendix Table A.1.

Table A.1 Values for parameters in Eqs. (2.1)–(2.25)

Parameter	Equations	Value						References
		China	US	Japan	EU	FSU	ROW	
α	Equation (2.1)	0.3	0.25	0.25	0.25	0.3	0.25	Eyckmans and Tulkens (2003)
D_0	Equation (2.2)	0.1371	0.0992	0.1057	0.1057	0.0771	0.144	Eyckmans and Tulkens (2003)
$b_{i,1}$	Equation (2.2)	0.15	0.07	0.05	0.05	0.15	0.10	Eyckmans and Tulkens (2003)
$\gamma_{i,a}$	Equation (2.3)	0.033	0.165	0.165	0.165	0.033	0.033	Nordhaus and Yang (1996)
$\delta_{i,a}$	Equation (2.3)	0.006	0.005	0.005	0.005	0.006	0.006	Nordhaus and Yang (1996)
$\delta_{i,k}$	Equation (2.4)	0.1	0.1	0.1	0.1	0.1	0.1	
η_i	Equation (2.5)	0.3	0.25	0.25	0.25	0.3	0.25	
ρ_i	Equation (2.7)	0.015	0.015	0.015	0.015	0.015	0.015	Eyckmans and Tulkens (2003)
τ_i	Equation (2.7)	0.198	0.198	0.198	0.198	0.198	0.198	
$\sigma_{i,t}$	Equation (2.8)	0.0007	0.0001	0.00006	0.0001	0.0007	0.0003	
$\gamma_{i,t}$	Equation (2.10)	0.033	0.165	0.165	0.165	0.033	0.033	Nordhaus and Yang (1996)
$\sigma_{i,t}$	Equation (2.12)	0.00075	0.00015	0.000068	0.00012	0.00072	0.00029	
ς_i	Equation (2.13)	0.22	0.22	0.11	0.2	0.22	0.51	
$\lambda_{i,FN}$	Equation (2.15)	0.93	0.88	0.83	0.87	0.90	0.88	
$a_{i,N}$	Equation (2.20)	3	2	2	2	3	3	van der Zwaan (2002)
$b_{i,N}$	Equation (2.21)	9	8	8	8	9	9	van der Zwaan (2002)
$a_{i,F}$	Equation (2.22)	3	3	3	3	3	3	van der Zwaan (2002)
$b_{i,F}$	Equation (2.23)	1	1	1	1	1	1	van der Zwaan (2002)
g_0[a]	Equation (2.24)	1	1	1	1	1	1	van der Zwaan (2002)
g_0[b]	Equation (2.24)	2	2	2	2	2	2	van der Zwaan (2002)
l_r[a]	Equation (2.25)	0.07	0.07	0.07	0.07	0.07	0.07	van der Zwaan (2002)
l_r[b]	Equation (2.25)	0.1	0.1	0.1	0.1	0.1	0.1	van der Zwaan (2002)

[a] Value for learning-by-doing in fossil-fuel technologies
[b] Value for learning-by-doing in non fossil-fuel technologies

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