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Efficiency or Equity? Simulating the Carbon Emission Permits Trading Schemes in China Based on an Inter-Regional CGE Model

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Keywords:
Greenhouse gas emissions; energy conservation; emission reduction; pollution; cap-and-trade mechanism

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Efficiency or Equity? Simulating the Carbon Emission Permits Trading Schemes in China Based on an Inter-Regional CGE Model

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Abstract

Energy conservation and greenhouse gas (GHG) abatement have been included in the national development strategy of China. However, the rigidity in command-and-control mechanisms and arbitrariness in assignment of GHG abatement burden across regions have caused unnecessary losses in both economic efficiency and social equity. In this paper, we use an Inter-Regional Dynamic CGE (IRD-CGE) model to simulate economic and welfare impacts of climate policies on national and regional level, including carbon intensity targets, regional emission constraints and cap-and-trade mechanism. Comparison among alternative emission reduction policy mechanisms indicates that emission trading scheme can not only moderate the economic and social welfare losses, but also improve social equity by decoupling the allocation of emission permits from economic optimization of emission reduction scheme. From this perspective, emissions trading bridges the concerns for economic efficiency and social equity, since emission permits could be reallocated as an income transfer so as to promote inter-regional equity, while economic efficiency is maintained.

1. Introduction

Since the beginning of this century, the tightening of domestic energy market, together with the pressure from international community for GHG abatement in China, has pushed Chinese policy makers to include energy conservation and GHG reduction into national development strategy. However, the growth in energy consumption and GHG emission in China has been reinforced during the industrialization and urbanization of China, which made it difficult to disentangle GHG emission with economic growth. From this perspective, climate policies and emission reduction activities in China must be designed and planned prudently so as not to halt economic growth either in the short and long run. Unfortunately, emission reduction in China so far is mainly carried out through command-and-control regulations and the GHG abatement burden had been assigned arbitrarily across regions and sectors. The rigidity and arbitrariness in policy schemes have caused dual losses in both economic output and social equity. The brutal power cut and production limit in some regions at the end of “11th FYP” period in order to meet the energy conservation target was as vivid illustration.

The conflict between concerns for economic efficiency on national level and social equity on regional level is one important reason for the difficulties in emission reduction in China. Provinces in China are highly diversified from each other in geologic, economic, technological and social features. The disparity not only diversifies difficulties and costs in GHG abatement across regions, but also intensifies inter-regional economic correlation. More importantly, from a dynamic perspective, the booming Chinese economy is going through structural transition, which implies rapid change in economic structure and differentiated growth path across regions. Since the emission reduction costs of regions are sensitive to industrial structure and energy intensity, they are also changing along with regional economic growth and structural change rapidly and differently.

Considering the regional disparity both from static and dynamic perspective, flexibility is required in climate policy schemes so as not to halt economic growth either in short and long run. China is addressing to reform climate policies in the 12th FYP: set differentiated regional emission reduction targets, and carried out emission trading pilot projects in 7 cities and provinces. At the early stage for policy designing, it is crucial to evaluate the costs for emission reduction under alternative climate policy schemes and to estimate their impacts on economic growth, social welfare, income distribution both on regional and national level systematically.

In this paper, we established a dynamic Computable General Equilibrium (IRD-CGE) model which contained detailed inter-regional economic correlation. Quasi Putty-Clay mechanism with heterogeneous capital stocks was introduced to model the dynamics of industrial structure change. By coupling carbon flow with energy flow, we modeled CO_2 emission and economic performances endogenously, and evaluated the economic and welfare impacts of different climate policies. Comparing the economic efficiency and social equity in alternative policy scenarios can provide reference for the design of climate policy mechanisms in China.

The rest of the paper is organized as follows: section 2 reviews related literatures; section 3 introduces the model structure and features; the simulation results of policy scenarios are discussed in section 4; and section 5 for conclusion.

2. Literature Review

Massive researches have been devoted to evaluating economic and social impacts of climate policies, as well as exploring the optimal policy schemes for China during the last decade. The emission reduction in China so far are carried out mainly through direct command for regional or industrial emission intensity, rather than total emission constraints, as can be find in the 11th and 12th FYP, as well as in the Copenhagen Commitment of Chinese Government, out of the concerns for uncertainty in future economic growth. In recent years, market oriented policies, especially C&T schemes, caught the attention of Chinese policy makers, for its economic efficiency. The “12th FYP” approved the pilot projects of emission trading system in 7 cities and provinces. Aside from practical experiments of pilot projects, theoretical estimation of the effects of policies can also provide important reference for policy designing.

Researches on market oriented climate policies dates back to early 1990s before the signing of the Kyoto Protocol, but the researches for China haven’t started since this century, among which CGE models are widely used for evaluation of the impacts and effects of climate and energy policies. Zhang (1996, 1998), Garbaccio et al. (1998), Xie & Saltzman (2000) and Vennemo et al. (2009) were the pioneers in using CGE models to evaluate the effects of climate policies in China. Some Chinese researchers and teams also established their own models (Zhai et al., 1999; Li and He, 2005; He et al., 2002; Zhong & Li, 2002; Wang et al., 2005; Yao & Liu, 2010, etc.) Other researches include Wang et al. (2003); Cao (2009); Liu & Wang (2009); Zhang & Li (2011); Yang et al. (2011) who estimated economic effects of carbon taxation and emission trading schemes with partial equilibrium methods.

As mentioned above, the conflict between concerns for economic efficiency and social equity is one important reason for the difficulties in emission reduction in China, and the problem is essentially related to the assignment of GHG abatement targets across regions and sectors. Inappropriate assignment is not only harmful for the incentives for emission reduction activities, but would also lead to unnecessary economic losses. Unfortunately, studies on the assignment of emission targets, or the allocation of emission permits are rather insufficient (Li et al., 2010; Yi et al., 2011; Yao et al., 2012), and none were carried out with macroeconomic models.

Considering the regional disparity in China, a multi-regional dynamic model is required for analyzing the assignments of emission burden across regions, for their impacts on national and regional economic output, social welfare, income distribution, etc. On the other hand, the rapid economic transition in the Chinese economy must be modeled prudently so as to estimate the impact of climate and energy policies on economic growth and industrial structure change. However, studies based on multi-regional dynamic CGE models for China are under-developed. Known inter-regional models include the DRCCGE model developed by the Development Research Center of the State Council (Li & He, 2010), and the large- scale CGE model developed by the Research Center on Fictitious Economy & Data Science of the Chinese Academy of Sciences (Li et al., 2010; Yuan et al., 2012), but these large-scale model have not been devoted to analyzing emission reduction on regional level.

One of the main obstacles for developing regional models for China is the lack of statistics and database for inter-regional economic correlation, including trade and factor flows. Li (2010) estimated the inter-provincial trade matrix of each industry with Gravity Models; Shi and Zhang (2012) established an Inter-provincial Input-Output model which addresses the input-output correlations between sectors and regions in detail. With reference to those studies, we refined the inter-regional economic correlation module in our model by taking geologic information, factor endowments, economic structure and consumers preference into account, and studied the assignment of emission targets across regions in China, which provides useful reference for the designing of climate policy for China.

3. Model Structure and Features

We established an Inter-Regional Dynamic Computable General Equilibrium (IRD-CGE) model and simulated the economic performances of each province in China from 2007 to 2020 recursively. The baseline of the model is calculate according to the *2007 Regional Input-Output Tables for China* (National Bureau of Statistics, NBS, 2011), and calibrated according to actual economic performances of provinces in 2007~2012. The model included 30 regions (all provinces but Tibet, Hong Kong, Macao and Taiwan), and each region has 42 production sectors, one representative household and one regional government. Labor (L) and capital (K) are two factors of production, while under emission constraint scenarios, a third factor – emission permit is also required for final energy input. The notation and settings of variables and parameters can be found in table A2 and A3 in Appendix II.

3.1. Production & demand module

Producing technologies are specified with Nested CES functions. Empirical study by Huang (2003) proved the applicability of nested CES functions, and pointed out that the three-layer KLEM nesting structure fits the reality of China best. As shown in Fig. 1, capital (*K*) and labor (*L*) are combined into the value-added bundle (*VA*) in the bottom layer with unitary elasticity of substitution; the value-added bundle is further combined with energy goods (*EEG*) in the mid-layer; and in the top layer, the *KLE* bundle is combined with intermediate bundle (*M*) to produce *Y*. Intermediates are employed with fixed proportion in the intermediate bundle, and each input corresponds to an Armington aggregate of domestic production (*D*), inflowed products from other regions in China (*INF*) and imported products (*IMP*).

The elasticity of substitution of each layers in the nested CES function is crucial for CGE models, and a lot of researches have been devoted to the estimation (Zheng & Liu, 2004 a,b; Lu & Zhou, 2008; Wu, 2010, etc.), among which, Zhang (2006) distinguished the scenarios with and without technology improvements, and estimated the elasticity of substitution among capital, labor and energy, which provided reference for our model. Besides, it’s noteworthy that the elasticity of substitution among energy goods and between energy bundle and value-added bundle are set smaller than unitary but larger than fixed proportional. Different energy types are substitutable for each other, but fuel switching must be accompanied with costly substitutions of machines and equipment. According to Wu (2010), we set the elasticity of substitution equals 0.5.

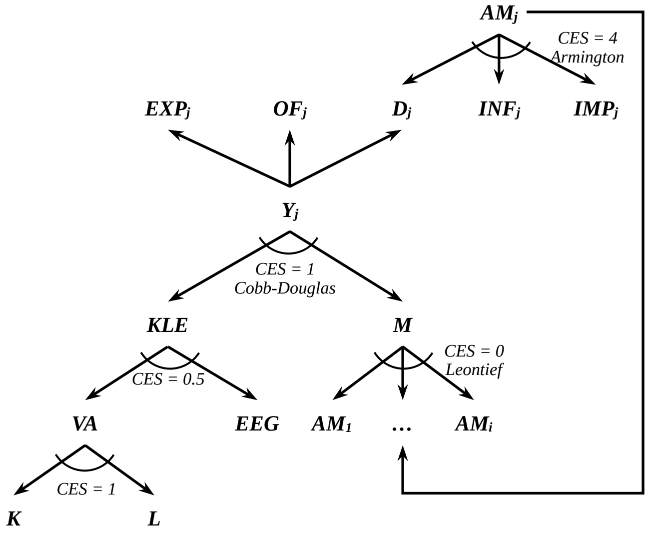


Fig. 1: KLEM Nesting Structure of Production Function

The demand structure of households is also specified with the following Nested Constant Elasticity of Transformation (CET) function:

$$\max_{\{WLF,DINV\}} U_r = D_r + \eta \cdot \ln WLF_r + (1-\eta) \cdot \ln SAV_r$$

$$WLF_r = \sum_i \varepsilon_{r,i} \cdot \ln cam_{r,i} + \sum_e \varepsilon_{r,e} \cdot \ln cae_{r,e} \;\; ; \;\; \sum_i \varepsilon_{r,i} + \sum_e \varepsilon_{r,e} = 1 \;\; ;$$

$$SAV_r = \min\left(\phi_{j \neq e} \cdot dam_{r,j \neq e}\right) \qquad \text{Eq. 1}$$

where WLF_r stands for regional consumption utility and SAV_r for saving utility; $1\text{-}\eta$ stands for the saving propensity. $cae_{r,e}$ and $cam_{r,i}$ are consumed energy and non-energy commodities (Armington aggregated); $dam_{r,j}$ stands for saved commodities; and ε stands for the share of each commodity consumed in total consumption expenditure.

The budget constraint of households is composed of capital income, labor income, and income transferred from the government (*TRANS*):

$$rk_r \cdot K + w_r \cdot L + TRANS_r = \sum_i pam_i \cdot cam_{r,i} + \sum_e pae_e \cdot cae_{r,e} + SAV_r + BOP_r \qquad \text{Eq. 2}$$

where BOP_r stands for current account balance of each region.

All taxes are assigned to regional government, so do emission permits. In the scenario where emission permits are auctioned, the income also adds to total income of governments. Governments consume commodities (*GOV*) and transfer the surplus to local households. Other demands including producers' intermediates demand (*PROD*), saving demand (*SAV*), and external demand (Export, and outflow), the structure is shown in Fig.2.

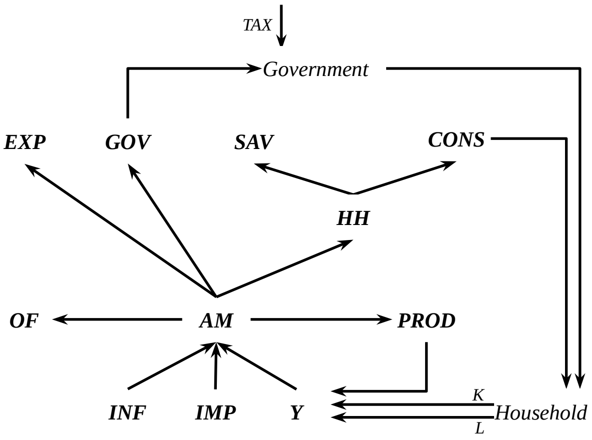


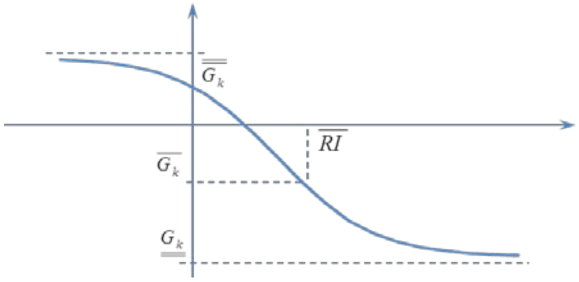
Fig. 2: Demand Structure

3.2. Recursive dynamic module

Economic growth was simulated recursively. In order to model the process of economic growth path and industrial structure change process, quasi-putty-clay capital accumulation mechanism was introduced in the model with heterogeneous capital stock. Specifically, capital stocks are set as sunk and non-flowable across regions and sectors while newly formed financial capitals are flowable across regions and sectors, and thus industrial structure change could only be carried out gradually through depreciation of old capital stocks and formation of new stocks. Total investment in each period equals the total saving in the preceding period which is determined by eq.1 (i.e. neo-classical macro-closure). The split of total investment across industries is determined by capital rate of return of each industry. Referred to the MONASH model (Dixon, 2002), we used a Logit function to map expected capital rate of return (*RIE*) to capital accumulation rate (g_i^k):

$$g_i^k = \frac{\underline{\underline{g_i^k}} + \overline{\overline{g_i^k}} \cdot e^{cgk\left(RIE_i - \overline{RI_i}\right)} \cdot \left(\overline{g_i^k} - \underline{\underline{g_i^k}}\right) \Big/ \left(\overline{\overline{g_i^k}} - \overline{g_i^k}\right)}{1 + e^{cgk\left(RIE_i - \overline{RI_i}\right)} \cdot \left(\overline{g_i^k} - \underline{\underline{g_i^k}}\right) \Big/ \left(\overline{\overline{g_i^k}} - \overline{g_i^k}\right)} \qquad \text{Eq. 3}$$

where $\overline{\overline{g_i^k}}$ and $\underline{\underline{g_i^k}}$ stand for the upper- and lower-limit of capital accumulation; $\overline{g_i^k}$ and $\overline{RI_i}$ stand for the average level of capital accumulation and rate of return; *e* is the base of the natural logarithm.



The actual capital rate of return RI_i^t is calculated as eq. 4:

$$RI_i^t = \frac{1}{1+\rho} \cdot \frac{RK_i^{t+1}}{PINV^t} + \frac{1-\delta}{1+\rho} \cdot \frac{PINV^{t+1}}{PINV^t} - 1 \qquad \text{Eq. 4}$$

where ρ is the subjective discount rate; δ is the depreciation rate; RK_i^t stands for the rental rate of capital stock in industry i in period t; $PINV_t$ stands for average cost of investment and is calculated as weighted average price of saved commodities in eq.1. From eq.4 we can find that the calculation of RI_i^t requires rental rate and investment cost for the next period $t+1$, which are expected adaptively:

$$RK_i^{t+1} = 0.4 * RK_i^{t-1} + 0.6 * RK_i^t ; \quad PINV^{t+1} = 0.4 * PINV^{t-1} + 0.6 * PINV^t \qquad \text{Eq. 5}$$

So that the investment to industry i in period t is:

$$INV_i^t = s \cdot \left(g_i^{k,t} + \delta\right) \cdot FXA_i^t \qquad \text{Eq. 6}$$

where FXA_i^t is the fixed capital stock, and s is deflator to make sure total investment equals total saving in the preceding period. And thus, the capital stock in next period would be:

$$FXA_i^{t+1} = (1-\delta) \cdot FXA_i^t + INV_i^t \qquad \text{Eq. 7}$$

3.3. Inter-regional economic interaction and correlation module

Small Economy Assumption is followed in modeling international trade of each region, i.e. international market demand/supply are infinite at exogenous international market prices, but not for domestic trade. In simplified multi-regional CGE models, an extra region (ROW) is introduced to serve as a transit for all the trade flows. It's a compromise since data for inter-regional trade are not readily available, but the simplification ignored the impact of difference in trade costs and preferences across regions, which could be crucial for determining trade flows (see Fig. 3).

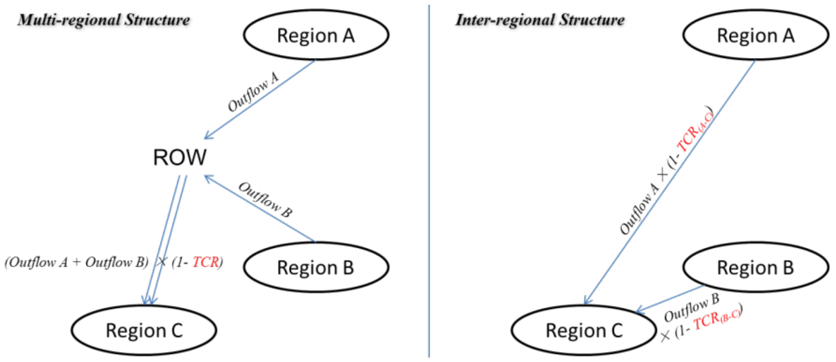


Fig. 3: Comparison between "Multi-Regional" and "Inter-Regional" Structures

In order to model inter-regional trade flow precisely, we need to estimate the inter-regional trade matrix. Firstly, we regressed a Gravity Model for the determinants for trade between two regions, and accordingly, split total outflow of each region provided in the Input-Output (I-O) table so as to form the rudimentary trade matrix. Finally, we rebalance the I-O table by cross-entropy approach (see Robinson & El-Said, 2000 for reference). See Appendix I for detail.

Considering the expansion of production scale and development of modern logistic industry, destination of domestic trade flow are set indifferent for producers, and thus, domestic trade flows are mainly determined by preferences of demands. A nested Constant Elasticity of Transformation (CET) utility function is used to model the preference structure of demanders, according to Armington (1969):

$$c_i = \left\{ \alpha_{\mathrm{i}1} \left[\alpha_{i2} D_i^{-\phi} + \alpha_{i3} \left(\left(\sum_i \theta_{ir} INF_{ir}^{-\delta} \right)^{-1/\delta} \right)^{-\phi} \right]^{-\rho} + \alpha_{\mathrm{i}4} IMP_i^{-\rho} \right\}^{-1/\rho} \qquad \text{Eq. 8}$$

where c_i is the combined consumption of non-energy commodity i; subscribe r stands for the source region of inflow; ϕ, ρ and δ are Armington elasticity of substitution of different nesting layers; and α, θ are cost share parameters. Energy goods were modeled differently. Since they are highly standardized with single utilization, energy goods of the same type from different sources are highly substitutable. So that we set a same elasticity of substitution for domestic and imported energy in Armington aggregation function, as Eq. 10 shows:

$$c_e = \left(\alpha_{e1} DS_e^{-\varepsilon} + \sum_r \theta_{er} INF_{er}^{-\varepsilon} + \alpha_{e4} IMP_e^{-\varepsilon} \right)^{-1/\varepsilon} \qquad \text{Eq. 9}$$

Fig. 4 shows the nesting structure of Armington functions for energy and non-energy commodities.

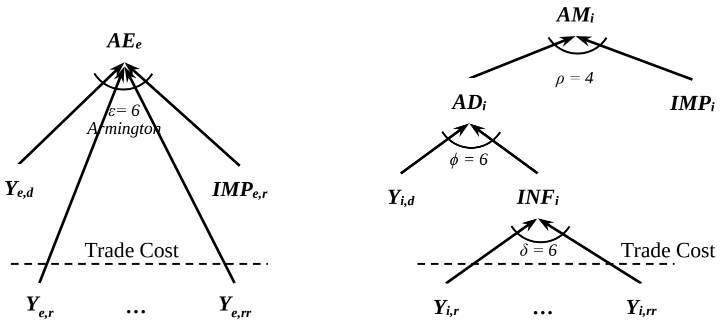


Fig. 4: Structure of Armington Aggregation

Trade cost is another key determinant for inter-regional trade flow, main part of which is transportation costs. According to *the Analysis of Logistic Operation* published by the China Federation of Logistics & Purchasing (CFLP, 2012), the total logistics costs of domestic trade in China was kept around 18% of GDP since this century. More importantly, the trade costs between regions are highly diverged, since the extremely wide territory of China. The longest inter provincial transport distance between Xinjiang and Heilongjiang is 38 time longer than the shortest between Beijing and Tianjin, and that also leads to highly diversified logistic costs. We estimated transportation cost for each industry with statistics published by the Ministry of Transportation and the NBS (See Appendix I for detail).

Aside from trade, factor flow is another important factor of inter-regional economic interaction. Unfortunately, statistics for inter-regional flow of capital or labor are very limited and insufficient for us to identify the origin of factor supply for each region. On the other hand, the substitutability between energy and capital/labor is highly controversial. Empirical evidences for China indicated that the substitutability between energy and capital or labor is much lower than that between capital and labor – in other words, change in energy costs would not have significant impact on capital and labor demand. From this perspective, no inter-regional flow of capital and labor are allowed in our model, and an sensitivity analysis is carried in section 5 in order to test its significance.

3.4. Energy and emission module

There are 5 energy industries included in our model: *Mining and Washing of Coal*; *Extraction of Petroleum and Natural Gas*; *Processing of Petroleum, Coking, Processing of Nuclear Fuel*; *Production and Supply of Electric Power and Heat Power*; and *Production and Supply of Gas*, providing coal (raw and washed coal), crude oil, natural gas (unprocessed), petroleum, coke, gasses (processed), electricity and heat. We can couple the flow of CO_2 with the process of extraction for primary energy extraction, conversion for secondary energy and final consumption of energy, i.e. the energy flow (as shown in Fig. 5).

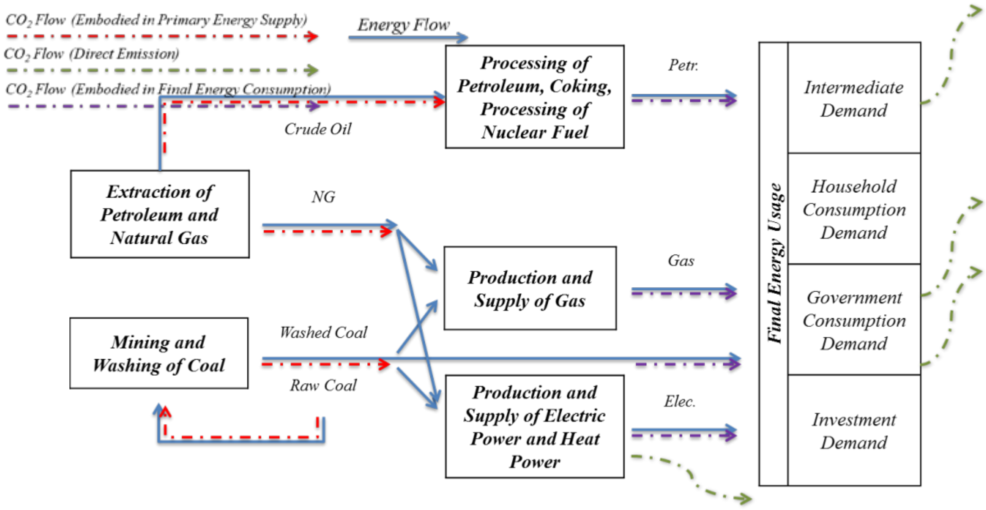


Fig. 5: The Coupling of Energy Flow and Carbon Flow

According to IPCC (2006), we tracked and calculated CO_2 emission embodied in final energy consumption. In order to couple CO_2 emission with energy consumption, we introduced a third factor, namely Emission Permits (*EM*) into our model, which is required to be combined with energy input in Leontief form before any energy could be used or consumed. Emission permits belong to regional governments and can be either auctioned or grandfathered to producers. The combination of energy input and emission permits internalized carbon emission into economic production and consumption of agencies, and thus enabled us to analyze the correlation between climate policies and economic activities. By levying input tax for emission permits, we can model carbon taxation policy scenario; by adjusting total supply and allocation of emission permits across regions, we can model emission constraints and corresponding allocation mechanisms. The combination of energy and emission permits, denominated as *EEG*, could be expressed as follow:

$$EEG = \theta\left(\sum_e \delta \cdot EC_e^{\gamma}\right)^{1/\gamma} = \theta\left(\sum_e \delta \cdot \left(\min\left(E_e, EM/EF_e\right)\right)^{\gamma}\right)^{1/\gamma} \qquad \text{Eq. 10}$$

4. Policy Scenarios and Simulation Results

During 2005~2010, each province in China carried out energy conservation and emission reduction activities as required in the 11th "Five-Year-Plan (FYP)". In June of 2011, the NDRC and NBS published the *Public Notice on the Completion of 11th FYP Regional Energy Conservation Targets*, from which we can find the historical energy consumption and energy intensity data for all provinces. In the *Work Program on GHG Controlling for 12th FYP Period* published by the State Council, the energy conservation and emission reduction targets are specified for each region for 2010~2015. And according to the Copenhagen commitment of Chinese government, the energy and carbon intensity would be further lowered to 40%~45% below the level in 2005 before 2020.

According to the above mentioned plans and commitments, we can calculate the carbon intensity target for each province in China from 2007 to 2002, as shown in table 1.

Table 1: Provincial carbon intensity target (2007 as the base year)

	2007	2008	2009	2010	2015	2020
Beijing	100%	94.01%	88.37%	83.07%	68.12%	62.30%
Tianjin	100%	95.39%	91.00%	86.81%	70.32%	64.31%
Hebei	100%	95.61%	91.41%	87.40%	71.67%	65.55%
Shanxi	100%	94.99%	90.23%	85.71%	71.14%	65.07%
Inner-Mongolia	100%	95.00%	90.25%	85.74%	72.02%	65.87%
Liaoning	100%	95.63%	91.46%	87.46%	71.72%	65.60%
Jilin	100%	95.14%	90.52%	86.12%	71.48%	65.38%
Heilongjiang	100%	95.45%	91.10%	86.95%	73.04%	66.80%
Shanghai	100%	95.64%	91.46%	87.47%	70.85%	64.80%
Jiangsu	100%	95.53%	91.25%	87.17%	70.61%	64.58%
Zhejiang	100%	95.63%	91.46%	87.46%	70.84%	64.80%
Anhui	100%	95.55%	91.30%	87.23%	72.40%	66.22%
Fujian	100%	96.47%	93.06%	89.78%	74.07%	67.74%
Jiangxi	100%	95.63%	91.44%	87.44%	72.58%	66.38%
Shandong	100%	95.13%	90.50%	86.09%	70.59%	64.57%
Henan	100%	95.61%	91.41%	87.39%	72.53%	66.34%
Hubei	100%	95.23%	90.69%	86.37%	71.69%	65.57%
Hunan	100%	95.53%	91.26%	87.19%	72.36%	66.19%
Guangdong	100%	96.48%	93.08%	89.80%	72.29%	66.12%
Guangxi	100%	96.75%	93.61%	90.57%	76.08%	69.58%
Hainan	100%	97.44%	94.95%	92.53%	82.35%	75.32%
Chongqing	100%	95.41%	91.03%	86.84%	72.08%	65.93%
Sichuan	100%	95.56%	91.32%	87.27%	71.99%	65.85%
Guizhou	100%	95.62%	91.43%	87.43%	73.44%	67.17%
Yunnan	100%	96.25%	92.63%	89.16%	74.45%	68.09%
Shaanxi	100%	95.58%	91.35%	87.30%	72.46%	66.28%
Gansu	100%	95.57%	91.34%	87.30%	73.33%	67.07%
Qinghai	100%	96.33%	92.80%	89.40%	80.46%	73.59%
Ningxia	100%	95.61%	91.42%	87.41%	73.42%	67.16%
Xinjiang	100%	95.61%	91.42%	87.41%	73.42%	67.16%

Note: Since we don't have provincial target for the period 2015~2020, we set the carbon intensity of each province decline evenly by the same proportion to meet the Copenhagen commitment.

Firstly, we estimated a scenario in line with the carbon intensity targets in table 1 as Business-as-Usual (BAU) scenario, and recited the total emission of each period and province. Then, we simulate alternative emission constraint policy schemes while keep the total emission in line with BAU scenario, and compare their economic impacts on regional and national level.

Table 2: Allocation of Emission Permits under Alternative Criterion

Allocation Criterion	*Emission Permits Allocated to Region r*
Regional Emission in BMK	$\tau \cdot \overline{EM}_r$

Regional Output in BMK	$\tau \cdot (\overline{OP}_r \big/ \sum_r \overline{OP}_r) \cdot \sum_r \overline{EM}_r$
Regional Welfare in BMK	$\tau \cdot (\overline{U}_r \big/ \sum_r \overline{U}_r) \cdot \sum_r \overline{EM}_r$

Note: BMK: benchmark scenario with no climate policy; τ:total emission reduction target;
$\overline{EM}_r$: regional emission; $\overline{OP}_r$: regional output; $\overline{U}_r$: regional welfare.

Emission constraint policies could be categorized on two dimensions: flexibility and allocation criterion of emission permits. We evaluated the policy effects of mandatory regional emission constraints with emission permits allocated across regions according to benchmark regional emission, output and welfare level[1] respectively. And for each allocation criterion, we further estimated the effects of emission trading schemes. Table 2 lists the allocation of emission permits under the three alternative criterions, and table 3 lists the notation, specification of scenarios.

Table 3: Settings of Scenarios and Simulation Results for 20% Emission Reduction

	Scenario	***Controlling Indicators***	***Flexibility***	***Allocation Criterion***
S1	NULL	No Climate Policy	/	/
S2	BAU	CO_2 Intensity Target	/	According to Current Policies & Plans
S3	EM_NT	Total Emission Constraint [1]	Non-tradable	Regional Emission in Base-year [2]
S4	EM_T		Tradable	
S5	OPT_NT		Non-tradable	Regional Economic Output in Base-year
S6	OPT_T		Tradable	
S7	WLF_NT		Non-tradable	Regional Welfare in Base-year
S8	WLF_T		Tradable	

Note: 1. Total emission constraints are set corresponding to regional emission in BAU Scenario for each year;
2. Base-year is 2007.

4.1. Business-as-Usual Scenario

In BAU scenario, regional CO_2 intensity targets are set according to policies, plans and commitments published/made by government authorities, as mentioned in the beginning of this sector. Intensity targets are enforced in the model by directly constraint the ratio of CO_2 emission and total economic output. According to the simulation results, the average GDP growth rate from 2007 to 2020 in BAU scenario is 8.26%, which is lowered by 0.28% by the emission intensity targets (the average growth rate in NULL scenario is 8.54%). Fig. 6 shows the comparison of BAU and NULL scenarios. From Fig.6, we can find that the emission reduction target of the 11th FYP decreased total emission and carbon intensity by 15.16% and 12.70% respectively (compared to base-year 2007), but caused 0.55% GDP loss in 2010. In 2015, the CO_2 intensity is required to be lowered by 29.05% compared to 2007, according to the 12th FYP. Fulfilling that target would lead to 34.12% reduction in total CO_2 emission and lead to 2.11% loss in GDP. And till 2020, according to the Copenhagen commitment, CO_2 intensity will be lowered by 35.46% compared to 2007 level, and will lead to 41.56% emission reduction and 3.31% of GDP loss.

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[1] Welfare level is the consumption value of households in the model, which, in benchmark scenario, equals total consumption numerically.

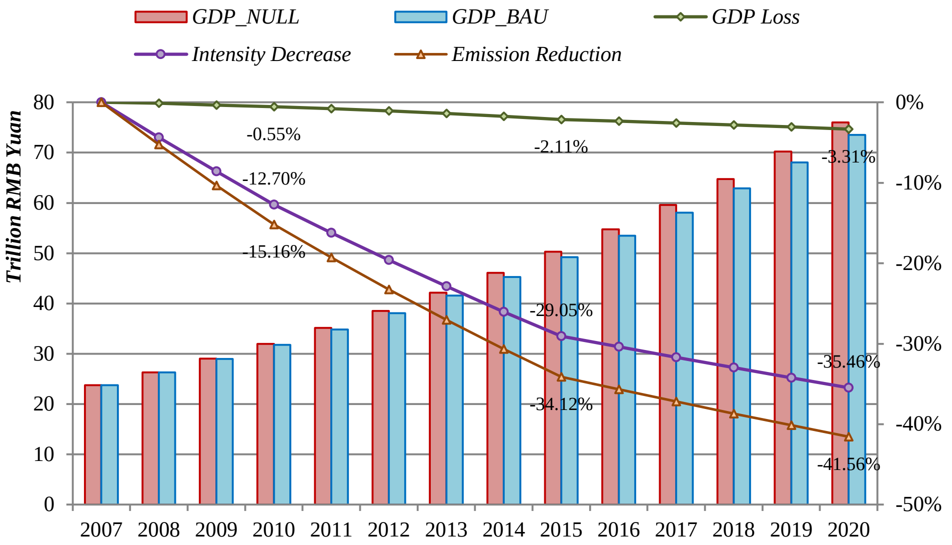


Fig. 6: Comparison of NULL and BAU Scenario

The economic losses represent economic costs of corresponding emission/intensity reduction targets. Fig.7 plots the nonlinear correlation between costs and emission/intensity reduction targets: higher emission/intensity reduction targets will lead to higher economic losses, and the slope increases indicating a non-linear correlation between emission reduction effect and marginal abatement costs – in other words, an ambitious emission reduction target would lead to severe economic losses.

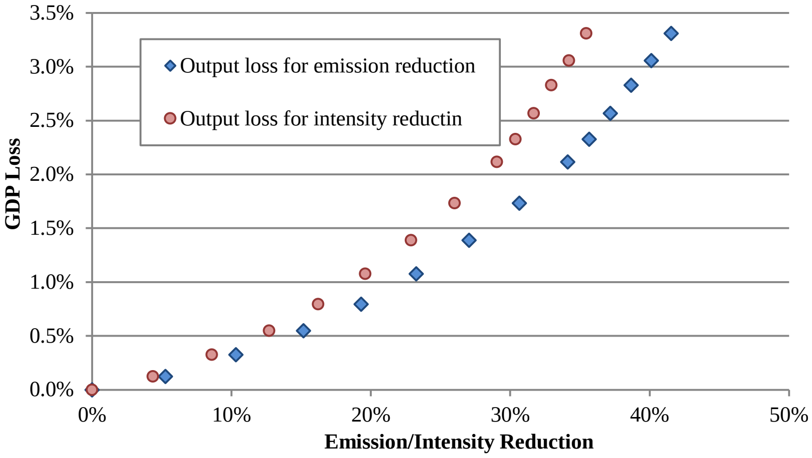


Fig. 7: Abatement Costs of Emission/Intensity Reduction Target

The economic impacts of emission reduction on regional level are diversified, due to different industrial structure, energy structure, technology level, resource endowments, etc. of each region. Fig.8 compares the regional CO_2 intensity reduction targets (%) and economic losses (%) in 2015. From fig.8 we can find that intensity targets are quite similar across regions, while corresponding economic losses are highly diversified. Energy intensive provinces and industrializing provinces, mainly distributed in Middle- and Northern-China areas are mainly infected by climate policies, including Shanxi, Gansu, Shaanxi, Heilongjiang, Liaoning, etc., while eastern areas are least sensitive to climate policies.

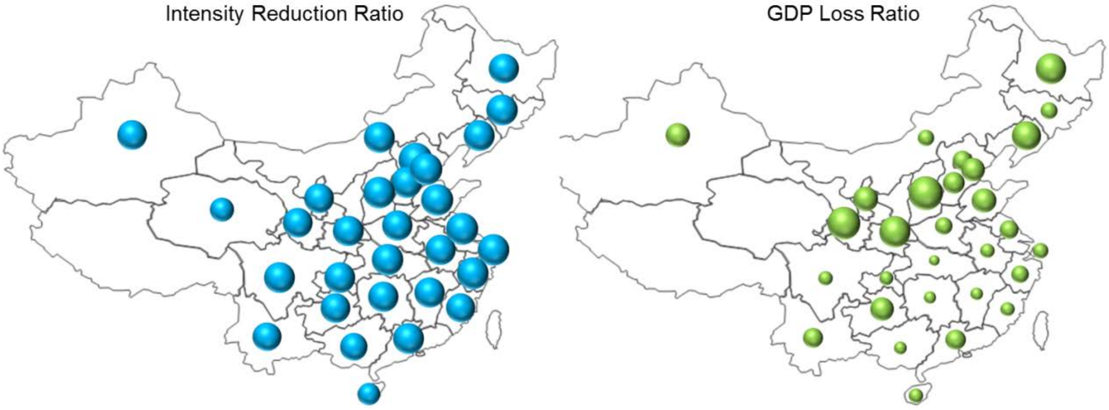


Fig. 8: Cross Regional Comparison of Economic Losses

As introduced in section 3.2, adjustment in industrial structure in our model is determined directly by the rate of return for capital, i.e. (expected) marginal production of capital. There are two main determinants for sensitivity of marginal capital production in certain industry to energy input cost, namely energy cost share, and price elasticity of demand for its product. China is in the middle of industrialization process which brought about rigid demand for industrial products. From fig.9, we can find that the general industrial structure in China is not affected observably by the climate policies. However, more detailed analysis revealed a 2% decrease in the output share of energy intensive sectors, as shown in fig.9.

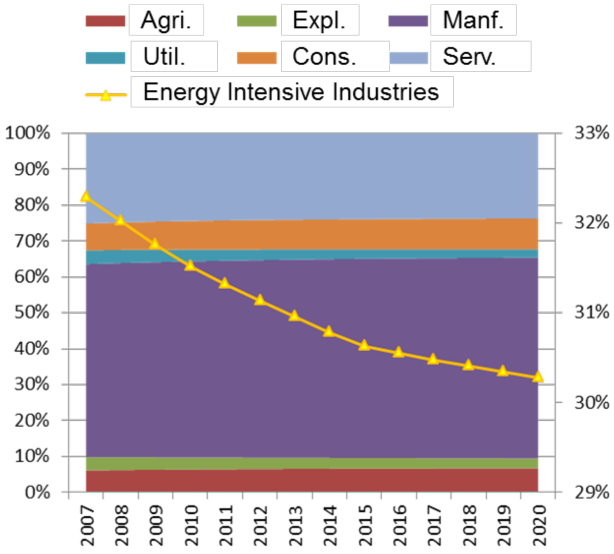


Fig. 9: Industrial Structure in BAU scenario

Industrial structure change is the autonomous adjustment of economic system to adapt policy change, which can mitigate the negative impacts of policy shocks. We simulated a scenario where the industrial structure are fixed for each region while all the other settings are identical to BAU scenario, and compared the economic output to that in BAU scenario. Fig. 10 shows the divergence.

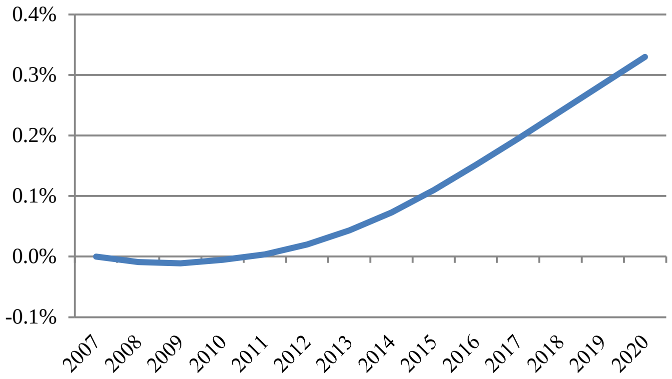


Fig. 10: Output Effect of Industrial Structure Change
$(GDP_{BAU}/GDP_{FX})-1$, where GDPBAU is the GDP in BAU scenario, while GDP_{FX} is the GDP in the fixed industrial structure scenario.

4.2. Total Emission Constraints with Non-tradable Permits

The social optimal allocation of resources lies in where marginal production of each factor is identical across sectors and regions. Under emission constraint scenarios, the marginal production of emission permits, i.e. the Marginal Abatement Cost (MAC) of producers is determined by the shadow price of constraints they have to fulfill. Considering the regional disparity in industrial structure, technical ability, energy intensity, fuel structure, endowment features, etc., none of the aforementioned allocation criterion (benchmark emission, output or welfare) could assure equivalent MAC for each region, and thus would lead to extra economic and welfare losses.

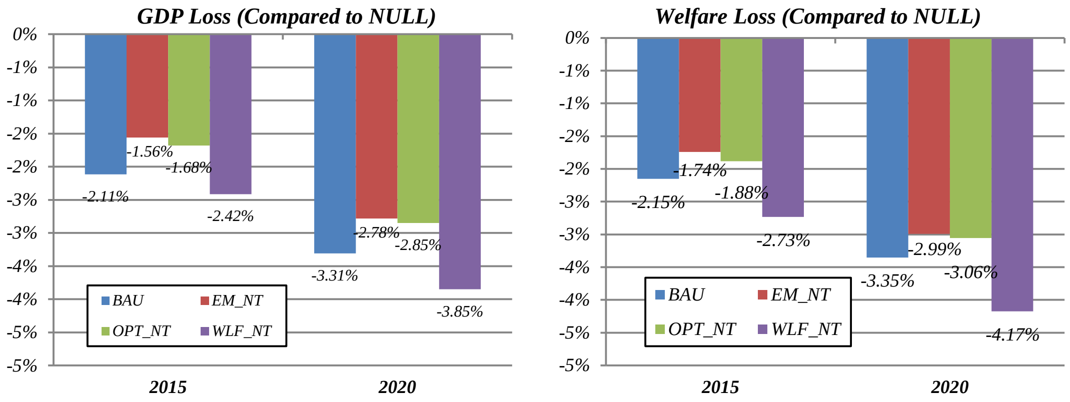


Fig. 11: Economic and Welfare Losses of Mandatory Emission Constraints

Fig. 11 shows the simulation results for sample periods. When the emission permits are allocated according to base-year emission (*EM_NT*), the economic output (GDP) losses in 2015 and 2020 for the same emission reduction targets as in BAU would be 1.56% and 2.78% respectively; and welfare losses would be 1.74% and 2.99%. When the permits are allocated according to base-year economic output (OPT_NT), the economic losses would be 1.68% in 2015 and 2.85% in 2020; while welfare losses would be 1.88% and 3.06% respectively. When the permits are allocated according to base-year welfare (WLF_NT), the economic losses would be the highest as 2.42% in 2015 and 3.85% in 2020; while welfare losses would be 2.73% and

4.17% respectively. From fig.9, we can see that for the same lever of total emission reduction, the economic and welfare losses are highly diversified with respect to emission permits allocation criterions: base-year emission and output criterions leads to superior economic and welfare impacts than the intensity targets in BAU scenario, while those for the base-year welfare criterion are inferior to BAU.

And besides, the wide divergence between the economic and welfare effects of alternative allocation criterions indicated that adjusting emission permits would lead to remarkable extra economic and welfare losses and that caused conflict between economic efficiency and regional equity.

4.3. Total Emission Constraints with Tradable Permits (Cap-and-Trade schemes)

If the emission permits could be traded across regions, agencies faced with a certain emission constraint in a certain region can purchase or sell permits from or to other regions so as to minimize their costs for fulfilling the emission constraints. The equilibrium would be reached when the Marginal Abatement Costs (MAC) of all regions and producers get equalized at a unique market price for emission permits – in other words, emission trading could assure the Pareto Optimum of production regardless of the initial allocation of emission permits.

Fig. 12 shows the emission and Marginal Abatement Costs (MAC) of each region before and after emission trading, when the emission permits are allocated across regions according to base-year emission level. Regions with high MAC in non-tradable scenario tend to emit more after emission trading scheme introduced into the system, and vice versa. Fig. 13 further reveals the correlation between MAC and emission reduction rate.

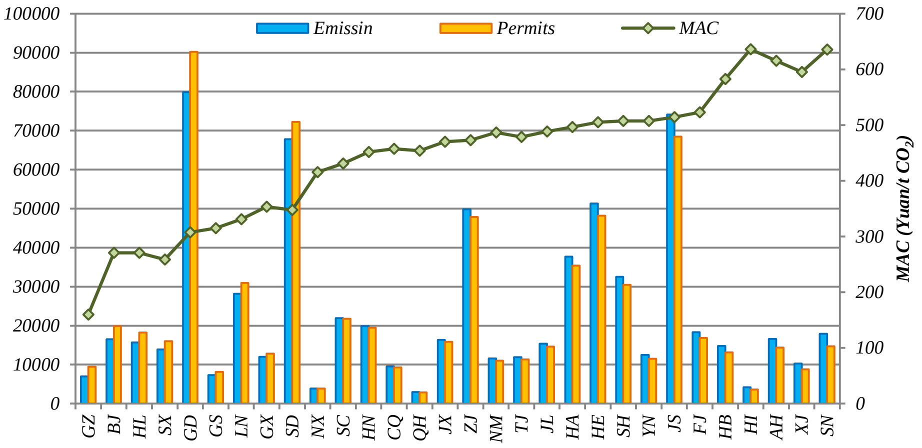


Fig. 12: Impact of Emission Trading Scheme on Regional Emission and MAC (2015)

Note: Regions sorted by emission reduction ratio (from highest to lowest)

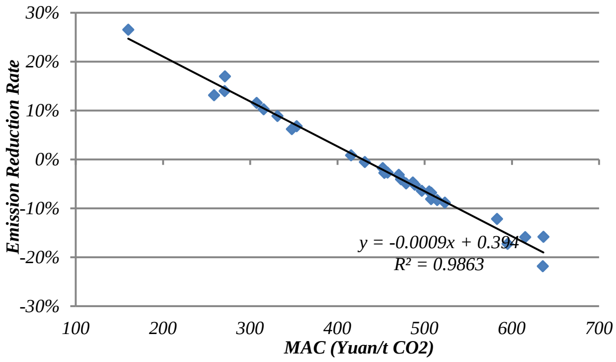


Fig. 13: Correlation between MAC and Emission Level

The economic and welfare effects of emission constraints under Cap-and-Trade scheme are superior to BAU scenario, regardless of the initial allocation of emission permits. When the emission permits are allocated according to base-year emission (*EM_T*), the economic output (GDP) losses in 2015 and 2020 would be 1.47% and 2.61%; and welfare losses would be 1.65% and 2.80%. When the permits are allocated according to base-year economic output (OPT_T), the economic losses would be 1.47% in 2015 and 2.59% in 2020; while welfare losses would be 1.64% and 2.77% respectively. When the permits are allocated according to base-year welfare (WLF_T), the economic losses would be 1.57% in 2015 and 2.77% in 2020; while welfare losses would be 1.71% and 2.91% respectively.

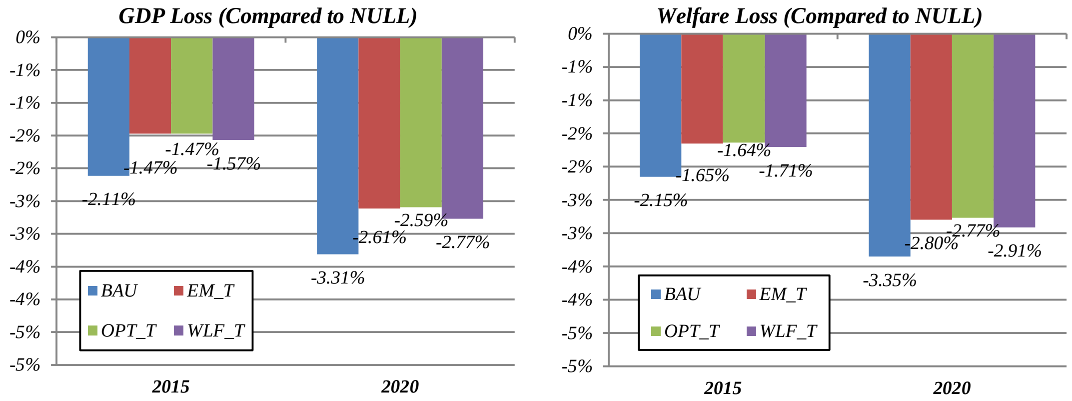


Fig. 14: Economic and Welfare Losses of Cap-and-trade Schemes

Comparing the scenarios with and without emission trading scheme (Fig. 15 shows the decrease of GDP growth rate and welfare growth rate in alternative climate policy scenarios, compared to NULL scenario), we can find that emission trading not only improved economic efficiency of emission reduction, but also, more importantly, narrowed the difference between alternative permit allocation criterions. According to fig. 15, emission trading scheme could recover 6.22% of the decrease in GDP yearly growth, and 6.56% of welfare growth under BMK emission allocation criterion; those figures would be 9.06% and 9.63% for BMK output criterion; 28.46% and 30.66% for BMK welfare criterion.

Fig. 15 also revealed the wide gap in economic and welfare effects of alternative permits allocation criterions when emission trading is not permitted. In 2015, the highest output loss in base-year welfare criterion (*WLF_NT*) is 35.51% higher than the lowest which is in the base-year emission criterion (*EM_NT*); and the highest welfare loss is 36.27% higher than the lowest. From this perspective, achieving regional equity by adjusting allocation of emission permits would lead to remarkable economic and welfare losses. However, with emission trading, the divergences between allocation criterions were narrowed to almost none. Since emission permits are valuable in emission trading market, altering the allocation of emission permits across regions would have direct impact on regional income and welfare. So that the central government can alter the allocation of permits intentionally to achieve inter-regional equity without sacrificing economic output or social welfare. In other words, emission trading scheme bridged the conflict between economic efficiency and inter-regional equity.

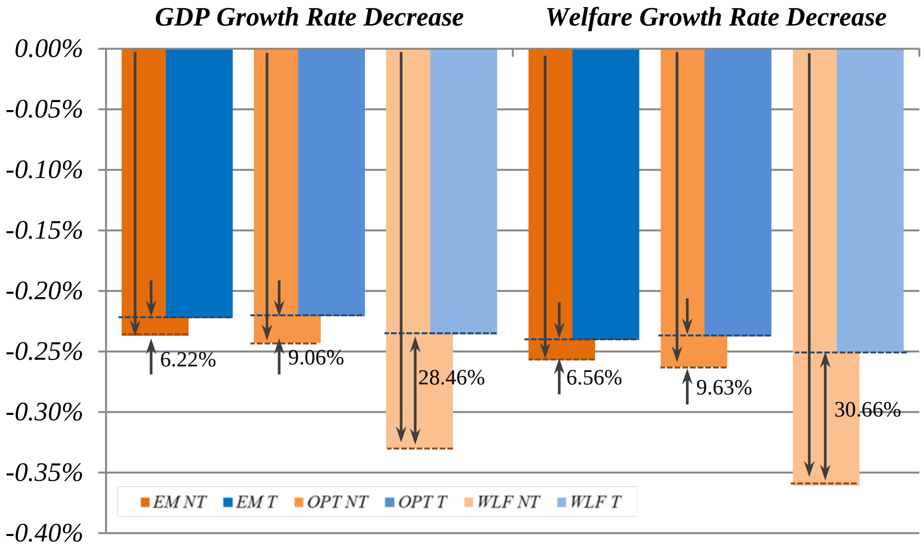
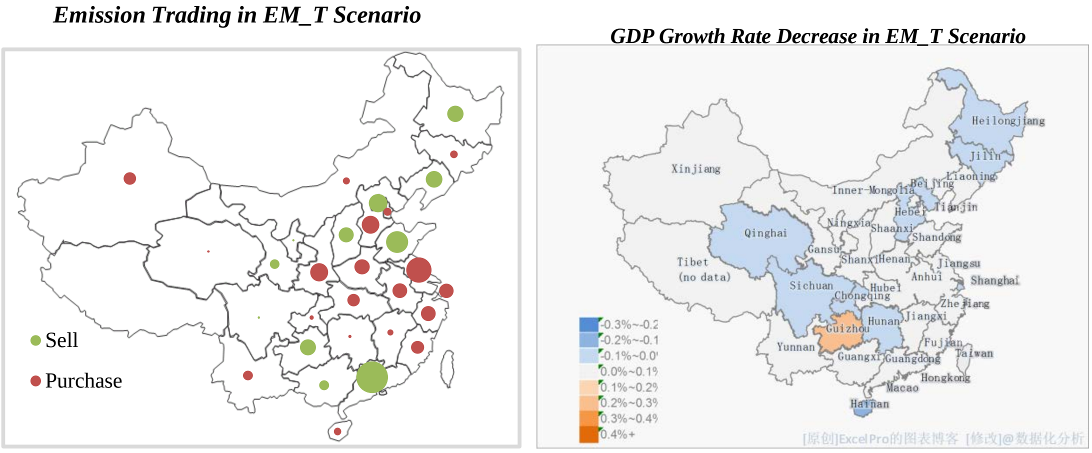


Fig. 15: Output and Welfare Effects of Emission Reduction with and without Emission Trading

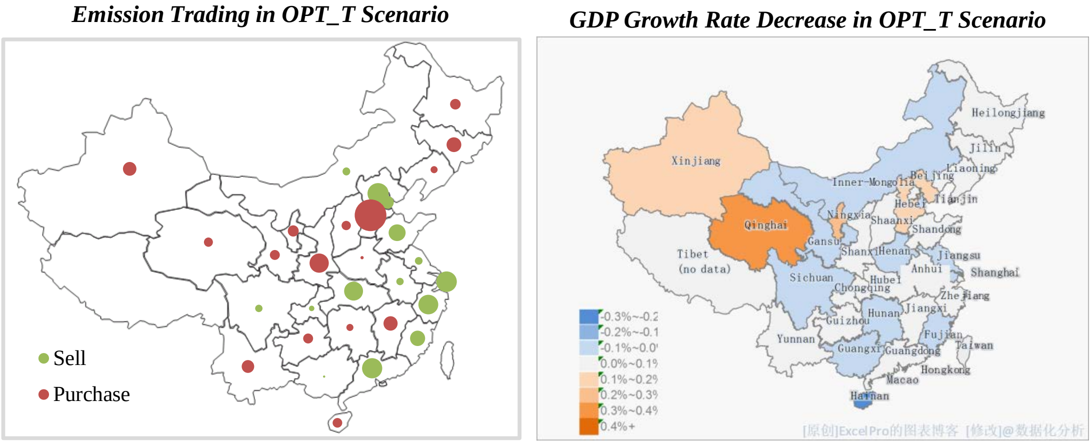
4.4. Regional Impacts of the Reallocation of Emission Permits

Emission trading system provides the tradable permits with financial values, and thus, alternating its initial allocation could have direct impact on income distribution across regions. Fig.16 to 18 shows the trade flow of emission permits and correlated regional economic effects of emission trading in alternative permits allocation criterion. Blue areas are where yearly GDP growth rate increased after the introduction of emission trading, compared to growth without emission trading; while orange areas are the opposite.


Emission Trading in EM_T Scenario

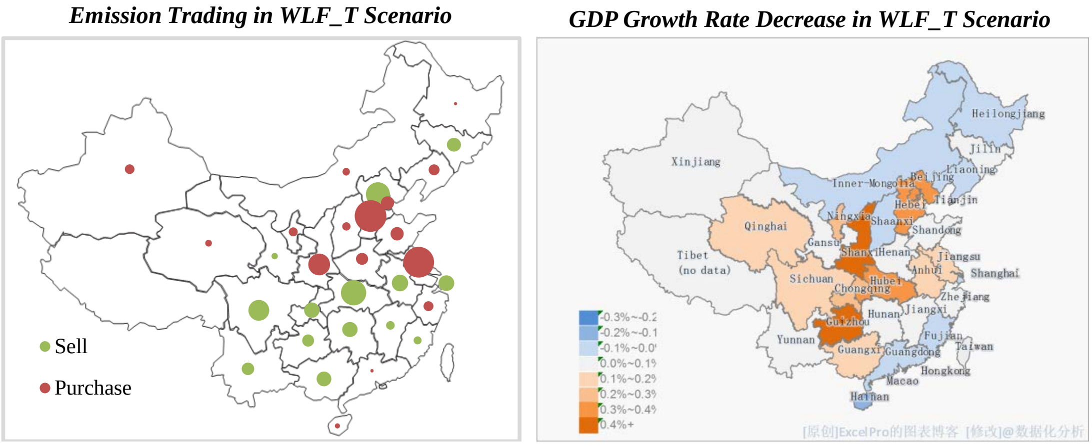
GDP Growth Rate Decrease in EM_T Scenario

Fig. 16: Emission Trade Flow and Its Economic Impact (EM_T)


Emission Trading in OPT_T Scenario

GDP Growth Rate Decrease in OPT_T Scenario

Fig. 17: Emission Trade Flow and Its Economic Impact (OPT_T)


Emission Trading in WLF_T Scenario

GDP Growth Rate Decrease in WLF_T Scenario

Fig. 18: Emission Trade Flow and Its Economic Impact (WLF_T)

From fig.16, we can find that under BMK emission criterion, the developed eastern coastal areas of China with low energy intensive, and thus high MAC would purchase permits from middle and northern areas. With emission trading system, almost all regions are better offed (higher yearly average GDP growth). Fig.17 shows the trade flow of OPT_T Scenario where emission permits are allocated according to BMK economic output level, which is roughly the opposite to the EM_T Scenario. Eastern coastal areas are less energy intensive and have higher economic output, so that they are provided with more permits to sell, while other less developed areas have to buy permits to meet their needs for energy consumption. Western areas are most affected with significant decrease in GDP growth rate. The BMK welfare criterion for emission permits allocation is more favorable to southern areas of China, while the economic growth in middle and western areas are most worsen offed.

Reallocation of emission permits would change the income distribution and thus alter total demand, unless the utility functions are quasi-linear or homothetic (Hurwicz, 1995; Mas-Colell et al., 1995), which is not the case in our model. Besides, our model took trade costs into account, so that change in regional income would affect inter-regional trade flow, and thus affect total output. Last but not least, since the saving propensity and capital productivity are different across regions, the change in income distribution would lead to differentiated economic growth path, both on regional and national level. The demand effect, trade cost effects and economic growth effect caused the limited difference among economic and welfare effects of alternative permits allocation criterions.

Conclusion and Policy Implication

In this paper, we modeled the correlation between energy consumption, CO_2 emission and regional economic performances with an inter-regional dynamic CGE model for China. On that basis, we simulated the economic and welfare effects of climate policies including carbon taxation, mandatory regional emission constraints and cap-and-trade scheme for emission permits, as well as the effect of altering allocation of emission permits.

In BAU scenario, the emission reduction target of the 11th FYP decreased total emission and carbon intensity by 15.16% and 12.70% respectively (compared to base-year 2007), but caused 0.55% GDP loss in 2010. In 2015, the CO_2 intensity is required to be lowered by 29.05% compared to 2007, according to the 12th FYP. Fulfilling that target would lead to 34.12% reduction in total CO_2 emission and lead to 2.11% loss in GDP. And till 2020, according to the Copenhagen commitment, CO_2 intensity will be lowered by 35.46% compared to 2007 level, and will lead to 41.56% emission reduction and 3.31% of GDP loss.

Under mandatory regional emission constraints, economic and welfare effects of emission reduction are sensitive to allocation of emission permits. Comparatively, the output and welfare losses under Cap-and-Trade scenarios are significantly lower than in mandatory emission constraint scenarios, regardless of allocation of the tradable emission permits. Since emission permits are valuable under Cap-and-Trade scheme, alternating its allocation could affect regional income, and thus affect regional welfare. Comparing the scenarios with and without emission trading scheme revealed that emission trading scheme not only improved economic efficiency of emission reduction, but also narrowed the gap between alternative permit allocation criterions, and thus bridged the conflict between economic efficiency and inter-regional equity. Given emission trading scheme, emission permits could be reallocated so as to transfer income across regions without extra economic losses.

The aforementioned conclusions provided important reference for the design of climate policies in China. Establishing and expanding emission trading scheme on national level will be beneficial for diminishing adverse impacts of climate policies and for maintaining stability of economic output in China. On the other hand, given emission trading scheme, emission permits could be adjusted in order to achieve inter-regional equity or narrowing regional income gap without sacrificing economic efficiency of climate policies.

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Appendix I: Estimating the Inter-regional Trade Matrices and Trade Costs

1. Estimation for the trade matrices

Data is the basis for all researches. Unfortunately, there are no complete databases or statistics about inter-regional trade in China. In order to establish the inter-regional CGE model, we have to estimate the trade matrices for each commodity. According to Li (2010), we analyzed key determinants for trade flows by a “Gravity Model” as follow:

$$A_{ij}^{g} = \phi\left(A_{iO}^{g}\right)^{\beta_1}\left(A_{Oj}^{g}\right)^{\beta_2}\frac{\left(G_i\right)^{\beta_3}\left(G_j\right)^{\beta_4}}{\left(D_{ij}\right)^{\beta_5}} \quad \text{..Eq. 11}$$

A_{ij}^{g} stands for the value of commodity *g* trafficked from region *i* to *j*; ϕ is a constant; A_{iO}^{g} stands for the total outflow of *g* from region *i*; A_{Oj}^{g} stands for total inflow of *g* to region *i*; G_i and G_j are GDP for *i* and *j* respectively, and D_{ij} is the distance between the two regions, defined as the shortest road traffic distance between the two regions according to geological information data. The trade flow data are quoted from *the Year Book of China Transportation and Communication*, and regional GDP are quoted from *the China Statistical Yearbook*.[2]

According to the gravity model, we can make the original trade matrix for each commodity *g* as $\left\{\overline{a}_{ij}^{g}\right\}$, where $\overline{a}_{ij}^{g}$ stands for the flow of commodity *g* from *i* to *j* in total outflow of g from *i*. Given the original trade matrices for all commodities, we can split the total outflow of g from *i* into inflows into other regions. Since the splitting cannot assure that total inflow of a region equals the inflow data originally provided in the regional I-O table, so that we need to adjust the data by Cross Entropy Approach. The purpose of Cross Entropy Approach is to minimize the information loss in the adjusted matrix $\{a_{ij}{}^{g}\}$:

$$\min\left(\sum_i\sum_j a_{ij}\ln\left(a_{ij}/\overline{a}_{ij}\right)\right),\ \text{s.t.:}\sum_j a_{ij}^{g} * IF_i^{g} = OF_j^{g},\ \sum_i a_{ij}^{g} = 1,\ 0 \le a_{ij}^{g} \le 1 \text{...Eq. 12}$$

Where IF_i and OF_j stands for inflow of *g* into *i* and outflow from *j*. Finally, we use Cross Entropy Approach again to adjust the I-O table for each region to make them balanced. For the detail of Cross Entropy Approach, please refer to Robinson & El-Said (2000).

2. Estimation for trade costs

Trade cost is another important determinant for inter-regional trade flow. The integration of domestic market, agglomeration of industries and development of modern logistic industry made inter-regional trade more and more important for Chinese economy. However, the

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[2] See Li Shantong (2010): *2002 Expanded Regional Input-Output Table for China – Compilation and Application* (Economic Science Press, 2010) for detailed introduction of estimation for the gravity model.

transportation costs for inter-regional trade are unneglectable, thanks to the vase territory of China. However, there are no databases or statistics that are readily available for detailed analysis of transportation cost on commodity level.

We quoted the turnover volume (TOV_{gt}) by commodity and by transportation, the total logistic costs (FRT_t) by transportation, and the average transport distance ($DIST_t$) by transport from *the Traffic Capacity & Volume Database* provided by "the Transportation Technology Information Resources Sharing Platform" of the Ministry of Transportation; quoted the total social material flow value (VTG) from *the China Transport Statistical Yearbook*. According to these data, we can estimate the trade cost of each commodity.

Firstly, split the total logistic cost into commodities according to turnover value:

$$FRT_{gt} = TOV_{gt} / TOV_t \times FRT_t$$

Secondly, split the total material flow value into commodities according to outflow values (OF_g) provided in I-O table:

$$VTG_g = OF_g / \Sigma_g OF_g \times VTG$$

Then further split the material flow value of each commodity into transportation according to the turnover volume by commodity:

$$VTG_{gt} = FRT_{gt} / \Sigma_t FRT_{gt} \times VTG_g$$

Given the average traffic distance, we can calculate the transportation cost (in percentage of original value):

$$FS_{gt} = FRT_{gt} / (VTG_{gt} \times DIST_t)$$

And finally, the average transportation cost for a unit of traffic distance would be:

$$FS_g = \Sigma_t (FS_{gt} \times TOV_{gt} / TOV_g)。$$

For service sectors, there're no data for travel expenses, so that we set the traffic cost as of 15%.

Trade costs are set as "iceberg costs" which is proportional to traffic distance. Denominate FS_i as the rate of trade cost to original value of traded goods, then a unit of outflow of commodity i from origin r would loss by $FR_g/(1+FR_g)$ before it reaches destination rr as inflow: $[1/(1+FR_i)]\ OF_{r,i} = INF_{rr,i}$. The trade costs are charged to demanders as markup in the price of inflow: $P_{INFr,i} = (1+FR_i)\ P_{OFr,i}$ .Table A1 is the detailed list for trade costs.

Table A. 1: Transportation Costs for Inter-regional Trade

Sector	Code	FS_i, %/1000 km

Agriculture, forestry, animal husbandry and fishery	01	13.19%
Coal mining and washing industry	02	151.84%
Oil and gas exploration industry	03	5.87%
Metals Mining and Dressing	04	26.60%
Non-metallic minerals and other Mining and Dressing	05	85.50%
Food manufacturing and tobacco processing industry	06	13.19%
Textile industry	07	19.27%
Textile, leather Down and Related Products	08	19.27%
Wood processing and furniture manufacturing	09	37.34%
Paper printing and Educational and Sports Goods	10	19.27%
Petroleum processing, coking and nuclear fuel processing industry	11	5.87%
Chemical Industry	12	8.52%
Non-metallic mineral products industry	13	41.85%
Metal smelting and rolling processing industry	14	7.90%
Fabricated Metal Products	15	7.90%
Equipment manufacturing industry	16	5.45%
Transportation equipment manufacturing	17	5.45%
Electrical machinery and equipment manufacturing	18	5.45%
Communications equipment, computers and other electronic equipment manufacturing	19	5.45%
Instrumentation and cultural and office machinery manufacturing industry	20	5.45%
Artwork and Other Manufacturing	21	222.34%
Waste recycling industry	22	222.34%
Heat and power generation industry	23	15.00%
Gas production and supply	24	15.00%
Water production and supply industry	25	15.00%
Service sectors	26~42	15.00%

Appendix II: Notation and Settings of Parameters and Variables

Table A. 2: Notation of Variables and Parameters

Production Module		***Inter-regional Trade Module***	
Output of commodity i in region r	Y_{ri}	*Inflow value of commodity i from r to tt*	$INF_{r,rr,i}$
Capital input for sector j	K_{ri}	*Import value of i in region r*	IMP_{ri}
Labor input for sector j	L_{ri}	*Export of i from region r*	EXP_{ri}
Energy e input for sector j	E_{rej}	*Outflow of i from region r*	OF_{ri}
Intermediary input for sector j	M_{rij}	***Policy Module***	
Demand Module		*Transfer payments in region r*	$TRANS_{r}$
Domestic supply of i	D_{ri}	*Output tax of sector j in r*	$TAXP_{rj}$
Consumption of i in region r	$CONS_{ri}$	*Emission permits used by sector j in r*	EM_{rj}
Government consumption of i in r	GOV_{ri}	*Emission permits allocated to r*	$\overline{EM}_{r}$
Investment: Gross capital formation	GCF_{ri} ;	***Producers' Activity Function***	
Revenue reserve	REV_{ri}	*Profit of sector j*	π_{j}
Energy and Emission Module		*Output price of j*	p_{j}
Bundle of energy and emission	EEG_{rj}	*Output volume of j*	y_{j}
Emission factor of energy e	EF_{e}	*Cost function (energy and emission not included)*	$C_{j}(y_{j})$
Total emission in region r	EM_{r}	*Energy price*	p_{e}
Purchased emission permits	EM'_{r}	*Energy input*	E_{ej}
Local price for emission permits	p_{em}		
price for emission permits on national market	p'_{em}		