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, absence of market-mechanism and arbitrariness in assignment of abatement burden across regions have caused unnecessary losses in both economic efficiency and social equity. In this paper, we established an Inter-Regional CGE model based on which we simulated economic output and social welfare impacts, on national and regional level, of climate policies including carbon taxation and emission constraints (with and without emission-trading).

The simulation results indicated a marginal abatement cost (MAC) of 166.19 Yuan/t CO_2 for 20% emission reduction in carbon taxation scenario, and will lead to 3.18% decrease in total output and 2.54% decrease in total welfare of China. While under emission constraints, economic and welfare effects are sensitive to the allocation of emission permits and to whether the permits are tradable. Comparison of the policy scenarios indicated that emission-trading scheme can moderate the economic and social welfare losses, regardless of the allocation of emission permits. More importantly, it also narrows the difference between economic and welfare losses of alternative allocation of emission permits. From this perspective, emission-trading bridges the concerns for economic efficiency and social equity, since emission permits could be reallocated as an income transfer mechanism, so as to promote inter-regional equity, while economic efficiency is maintained. In the last scenario, we model the allocation of emission permits which equalizes welfare losses of emission reduction across regions.

1. Introduction

The tightening of domestic energy market, together with the pressure from international community for GHG abatement in China, has pushed Chinese policy makers to consider energy conservation and GHG reduction as national development strategy. On the other hand, the growth in energy consumption and GHG emission in China has been strengthened by the industrialization and urbanization process. As such, emission reduction activities need to be designed and planed prudently so as not to disturb economic growth in the long run. Besides, provinces in China are highly diversified in economic, technological and social features. The regional disparity also challenged policy makers by diversifying difficulties in GHG abatement. The harmonization between concerns for economic efficiency and inter-regional equity requires comprehensive, systematic and in-depth studies.

However, emission reduction in China so far, is mainly pushed through command-and-control regulations. Besides, the assignment of GHG abatement burden was also arbitrage. The rigidity and arbitrariness in regulations led to remarkable dual losses in economic output and social equity, which was illustrated vividly by the brutal power cut and production limit in some regions at the end of "11^{th} FYP" period in order to meet the energy conservation target.

So that it is quite meaningful to evaluate and compare the economic and welfare impacts of climate policies systematically, which is precisely the intention of this paper. We established an Inter-Regional Computable General Equilibrium (IRCGE) model, and modeled correlation between CO_2 emission and economic production endogenously by coupling carbon flow with energy flow. On that basis, we evaluated the economic and welfare impacts, on national and regional level, of different climate policies including carbon taxation, mandatory regional emission constraints and cap-and-trade (C&T) schemes. Alternative allocations of emission permits were also analyzed for their impact on total and regional welfare. Comparing the economic efficiency and social equity in alternative policy scenarios provided reference for the design of climate policies 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

The emission reduction target in China has been specified in the 12^{th} FYP, and in Copenhagen, however the required policies are still bewildering and controversial. Massive researches have been devoted to evaluating economic and social impacts of climate policies, as well as exploring the optimal policy schemes for China. Market oriented policies, especially carbon taxation and C&T schemes are the most prevailing policy schemes, and they are also the two most important choices on the table of policy makers in China. The "12^{th} FYP" approved the experimental emission trading system in 7 cities and provinces; carbon taxation is also under discussion. Researched by Cao (2009) and Liu & Wang (2009) indicated that C&T is more suitable to China in the short run, but the taxation is superior in the long run. Wang et al. (2003); Zhang & Li (2011); Yang et al. (2011) also analyzed the emission and economic effects of those two policy schemes.

Considering the wide and complicated transmission mechanisms of energy and climate policies to affect macroeconomic performances, CGE models are widely used for policy evaluation in the field of energy conservation and emission reduction. CGE models for China are developed since late 1990s, and 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.) The existing researches were mostly focused on policy evaluation while the settings for policy scenarios were rough, which hindered those models for providing direct references for practical policy making.

One of the most important and urgent problems in climate policy in China is the assignment of abatement targets across regions and sectors. Considering the aforementioned regional disparity and the rigidity in policy mechanisms, 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.

A multi-regional model is required for analyzing the assignment of emission targets across regions. However, studies based on multi-regional CGE models for China are under-developed, and mostly based on large-scale models including the DRCCGE originally established by the Development Research Center of the State Council (Li & He, 2010); multi-regional 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 IRCGE 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 a static IRCGE model whose benchmark scenario is calibrated according to the *2007 Regional Input-Output Tables for China* (National Bureau of Statistics, NBS, 2011). 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

Producers employ capital (*K*), labor (*L*) and input intermediaries (*M*) to produce a certain product *Y*. The technologies are described with Nested Constant Elasticity of Substitution (CES) production functions, with the prevailing KLEM nesting structures, as shown in Fig. 1. At given price set of all input and output, producers maximize their profits by determining the optimal input.

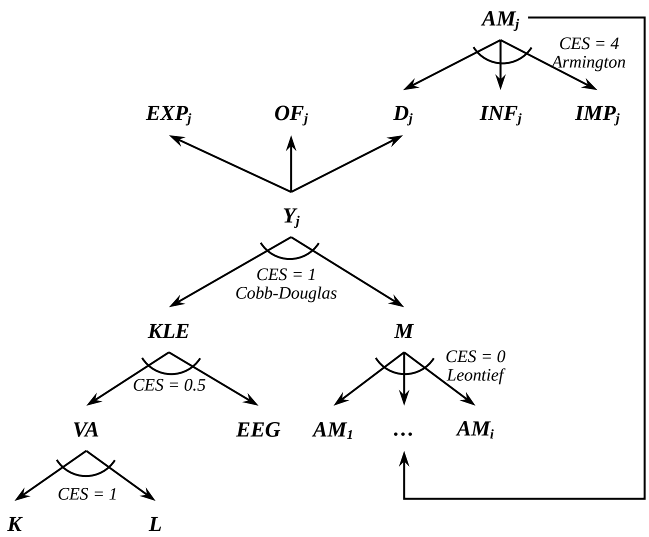

Fig. 1: KLEM Nesting Structure of Production Function

Note: M stands for intermediary input, which is composed of home-made products (D_j), products inflowed from other regions in China (INF) and imported goods (IMP); other input including capital (K), labor (L) and Energy (E). Output (Y) is used for domestic supply (D_j), outflow (OF) and export (EXP)

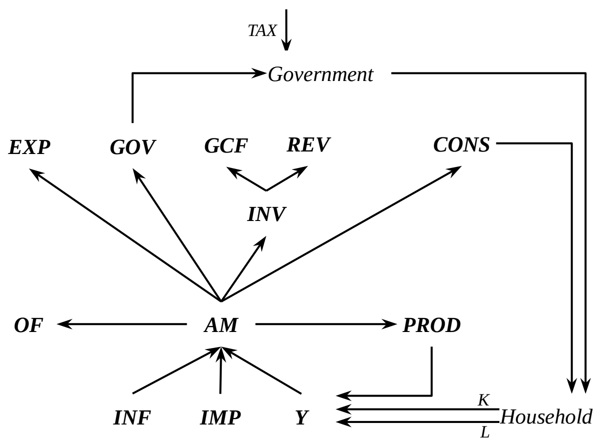

Fig. 2: Demand Structure

Total demand is composed of household consumption (*CONS*), government consumption (*GOV*), intermediary demand (*PROD*), investment (gross capital formation, *GCF*; revenue reservation, *REV*) [1] and external demands (export and outflow). The government levies production tax (*TAXP*) and carbon tax (*TC*) on agencies, and transfers the surplus to households. Under emission constraint scenarios, the emission permits are also possessed by the governments. Fig. 2 shows the standard structure of demands.

3.2. 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). 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.

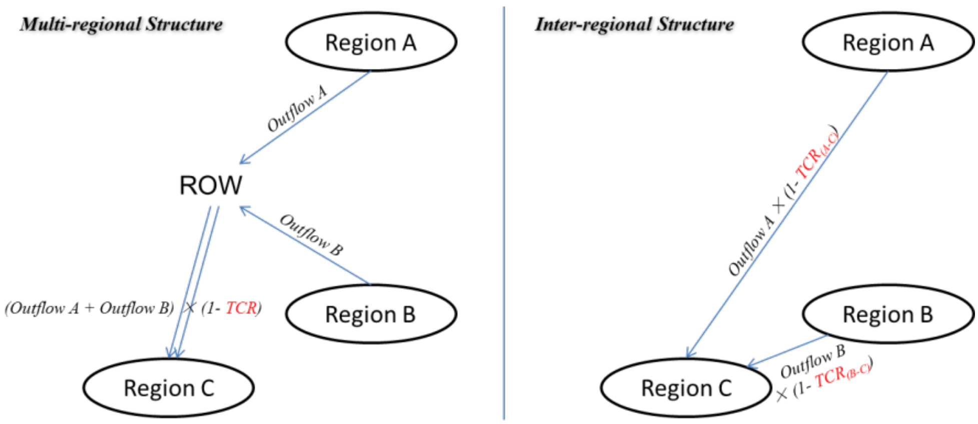

Fig. 3: Comparison between "Multi-Regional" and "Inter-Regional" Structures

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):

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[1] There are no inter-temporal optimization in the static model we established here, so that investment and foreign borrowing (i.e. balance of payments for international trade, *BOP*) were fixed at benchmark level, and deduced from households income as leakage.

$$c_i = \left\{ \alpha_{i1} \left[\alpha_{i2} D_i^{-\phi} + \alpha_{i3} \left(\left(\sum_i \theta_{ir} INF_{ir}^{-\delta} \right)^{-1/\delta} \right)^{-\phi} \right]^{-\rho} + \alpha_{i4} IMP_i^{-\rho} \right\}^{-1/\rho} \quad \text{..........................Eq. 1}$$

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:

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

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

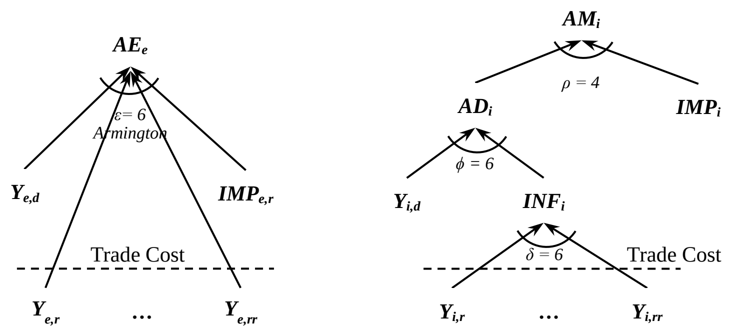

Fig. 4: Structure of Armington Aggregation

AE stands for aggregated energy goods; AM for non-energy goods

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.

3.3. 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).

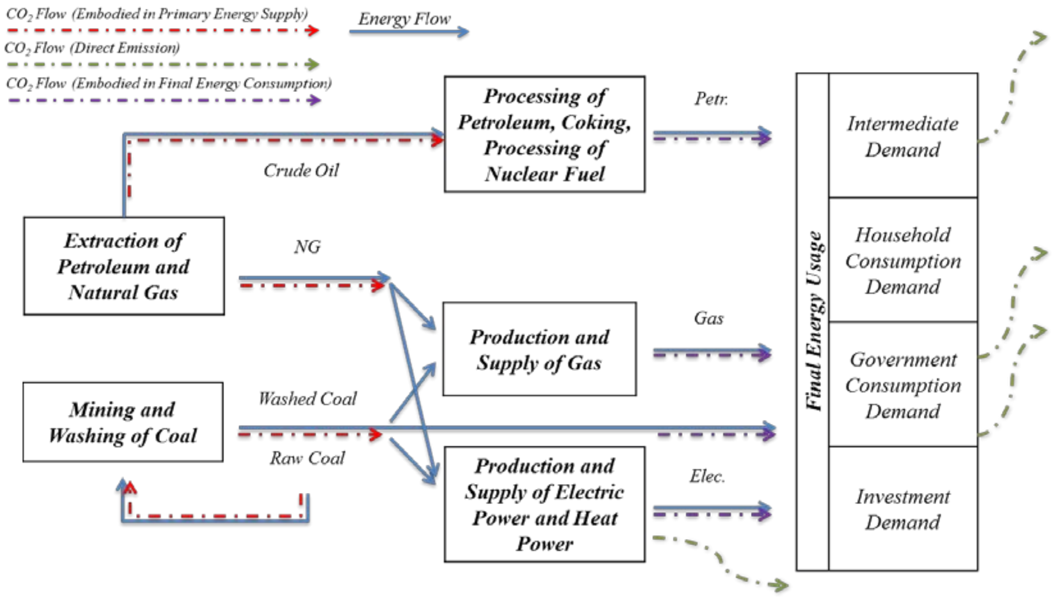

Fig. 5: The Coupling of Energy Flow and Carbon Flow

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:

$$EEG = \theta\left(\sum_e \delta \cdot EC_e^{\gamma}\right)^{1/\gamma} = \theta\left(\sum_e \delta \cdot \left(\min\left(E_e, EM/EF_e\right)\right)^{\gamma}\right)^{1/\gamma} \quad \text{..........................Eq. 2}$$

4. Policy Scenarios and Simulation Results

Carbon taxation, mandatory regional emission constraints and C&T scheme are the most widely used climate policies. As analyzed in section 3, each policy has different mechanism, and thus has different economic and welfare effects. Besides, climate policies would also affect equity across regions with respect to income, welfare and economic development.

Firstly, we simulated a series of carbon taxation scenarios with alternative tax rate (0 ~ 400 Yuan/t CO_2), and recited the CO_2 emission reduction rate corresponding to each tax rate. Secondly, we simulated emission constraint scenarios by limit the total supply of emission permits according to the emission reduction rates in carbon taxation scenarios, in order to assure the comparability between scenarios. Given the simulation results, we compared their economic and welfare effects on national and regional level.

Emission constraint policies could be further 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[2] respectively. And for each allocation criterion, we simulated the effects of emission trading schemes. And finally, we simulated a special allocation criterion which equalizes welfare losses across regions under 20% emission reduction targets.

Table 1: 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.

Table 1 lists the allocation of emission permits under the three alternative criterions, and table 2 lists the notation, specification of scenarios. The marginal abatement costs and output/welfare losses of 20% emission reduction in all the scenarios are also listed.

[2] Welfare level is the value of household welfare equation in the model, which, in benchmark scenario, equals total consumption numerically.

Table 2: Settings of Scenarios and Simulation Results for 20% Emission Reduction

Scenario	*Controlling Indicators*	*Flexibility*	*Allocation Criterion*	*MAC (yuan/t CO_2)*	*Output Loss (%)*	*Welfare Loss (%)*
S1	Carbon Taxation: 0~400 Yuan/t CO2 (20 levels)	/	/	166.19	3.18	2.54
S2	Emission Constraint: 0~37.16% Reduction (corresponding to reduction rate of each carbon tax rate)	Mandatory (Non-tradable)	BMK Emission	/	3.24	2.58
S3			BMK Output	/	3.36	3.73
S4			BMK Welfare	/	4.12	3.98
S5		Cap-&-Trade (Tradable)	BMK Emission	165.5	3.19	2.54
S6			BMK Output	166.1	3.24	2.52
S7			BMK Welfare	165.2	3.16	2.49
S8	Emission Constraint: 20% Reduction	Tradable	Equalize Welfare Losses Across Regions	167	3.32	2.59

4.1. Carbon taxation

Under carbon taxation scenario, the tax rate *tc* equals the MAC. From this perspective, we can plot the MAC curve by simulating the emission reduction rate under different carbon tax rate, as shown in Fig. 6. We can see from the figure that MAC increases along with emission reduction rate, and the slope increases, which indicated a non-linear correlation between emission reduction effect and MAC – in other words, an ambitious emission reduction target would lead to severe economic losses. The simulation results also indicated an MAC of 166.19 Yuan/t CO_2 for 20% emission reduction; and about 199.76 Yuan/t CO_2 of MAC for 20% decrease in carbon intensity. The difference is caused by output decrease: a certain percentage of emission reduction would lead to decrease in output, and thus, cause lower decrease rate in carbon intensity; for the same percentage of decrease, the total emission should be reduced further, and lead to higher marginal abatement cost. If we assume a yearly 9% growth in China with industrial structure kept the same as in the benchmark, then fulfilling the commission Chinese government made in the Copenhagen Summation, i.e. a 40% reduction in carbon intensity in 2020 compared to 2005, would lead to 7.72% of output decrease, and 9.07% of welfare loss; while comparatively, a 40% decrease in total emission would lead to 7.15% of output decrease and 8.08% of welfare loss, which is lower than in the intensity target scenario. Since the MAC for all regions and sectors are equalized under carbon taxation scenario, the equilibrium is Pareto optimal by definition.

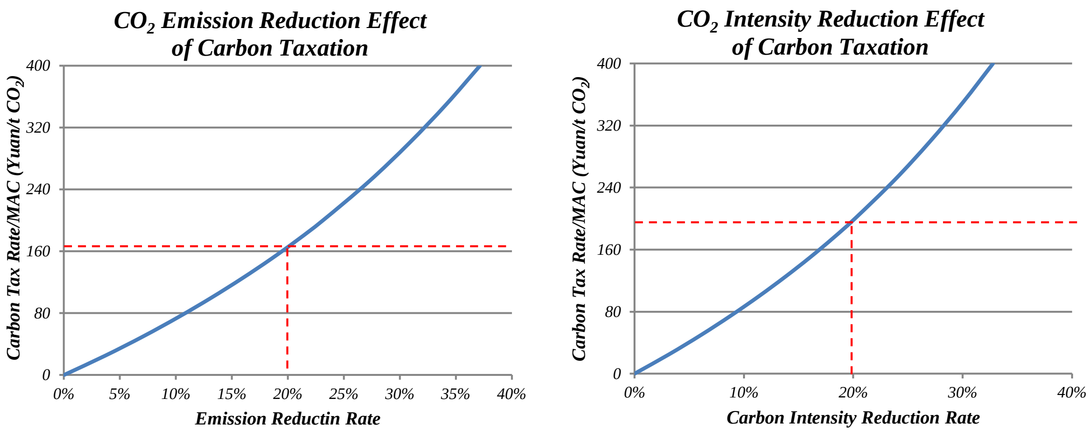

Fig. 6: Marginal Abatement Cost Curves

4.2. Mandatory regional emission constraints (non-tradable)

Under emission constraint scenarios, the 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.

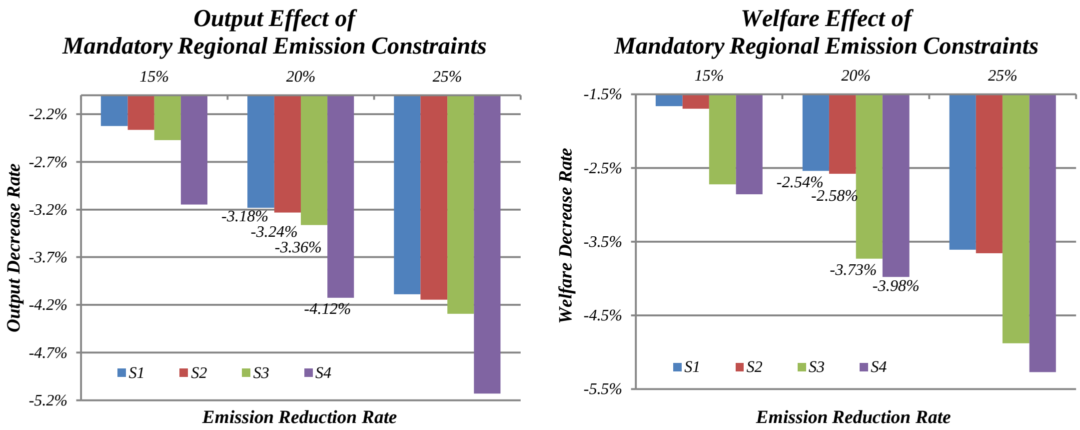

Fig. 7: Output and Welfare Effect of Mandatory Regional Emission Constraints

Fig. 7 shows part of the simulation results. Under carbon taxation scenario (*S1*), 20% emission would lead to 3.18% output loss, and 2.54% welfare loss. Under Mandatory regional emission constraints, when the emission permits are allocated according to BMK emission (*S2*), the output and welfare losses for the same rate of emission reduction would be 3.24% and 2.58% respectively; when the permits are allocated according to BMK output, the economic and welfare losses would be 3.36% and 3.73% respectively; when the permits are allocated according to BMK welfare, the economic and welfare losses would be the highest as 4.12% and 3.98%. According to Fig. 7, we can see that for the same lever of total emission reduction, the economic and welfare losses of regional emission constraints were higher than those of carbon taxation.

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. Cap-and-Trade schemes

If the emission permits could be traded across regions, producers of 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 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.

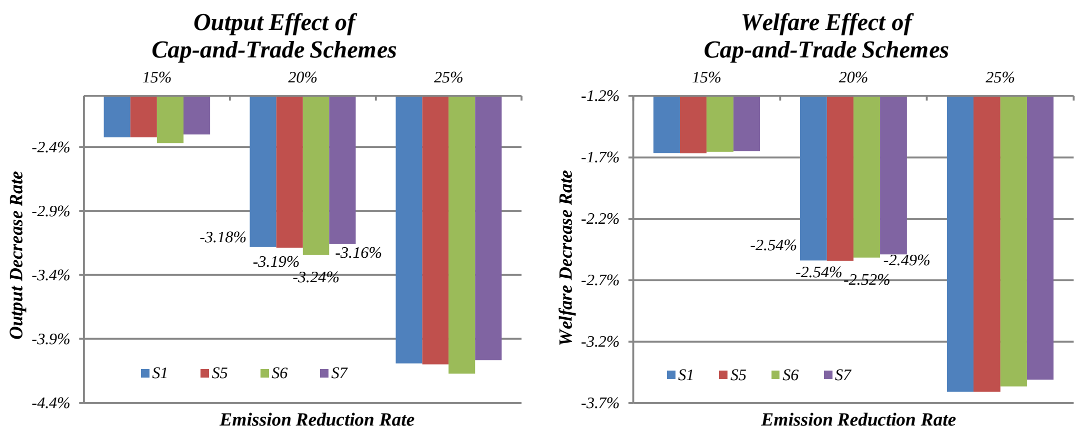

Fig. 8: Output and Welfare Effect of Cap-and-trade Schemes

Simulation results indicated that for 20% emission reduction, output losses would be ranged from the highest of 3.24% (S6) to the lowest 3.16% (S7); and the welfare losses would be ranged from the highest of 2.54% (S5) to 2.49% (S7).

It's also noteworthy that under emission trading scheme, emission permits are valuable and thus alternating the initial allocation could have direct impact on budget constraints of consumers in different regions. The income transfer due to reallocation of emission permits would change the demand structure, and thus alter total demand, unless the utilities functions are quasi-linear or homothetic (Hurwicz, 1995; Mas-Colell et al., 1995) which are not the case in our model. Besides, the IRCGE model we established in this paper also took trade costs into account, so that change in regional income would affect inter-regional trade flow, and thus affect general output. The change in demand structure and trade costs are the main reasons for the slight difference between economic and welfare effects of alternative allocation criterions under emission trading scenarios.

4.4. Comparison between mandatory regional constraints and Cap-and-trade scheme

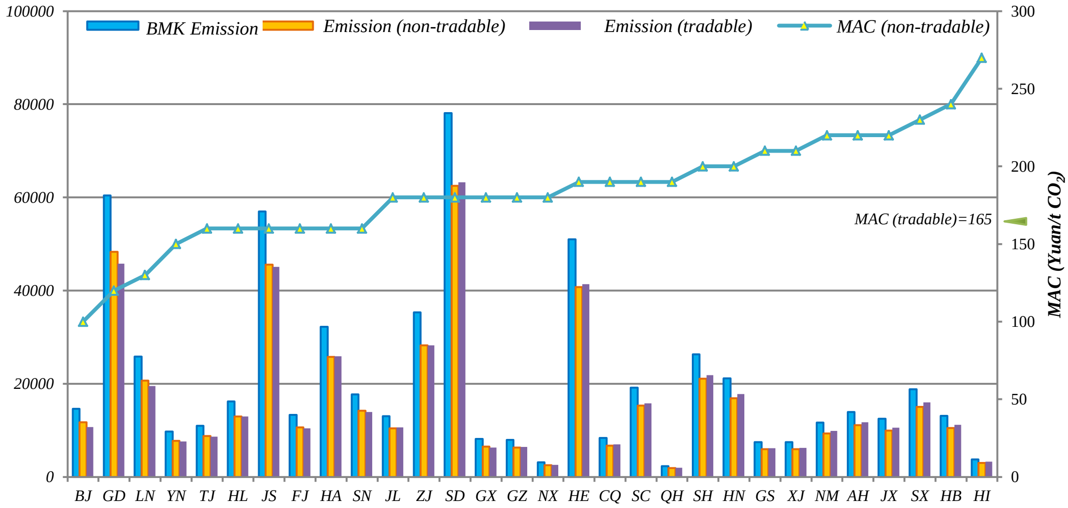

Fig. 9: Impact of Emission Trading Scheme on Regional Emission and MAC

Note: Emission permits allocated according to BMK emission

Fig. 9 shows the emission and MAC of each region before and after emission trading. Regions with high MAC in non-tradable scenario tend to emit more after emission trading scheme introduced into the system, and vice versa. Fig. 10 further proved the positive correlation between MAC and emission reduction rate.

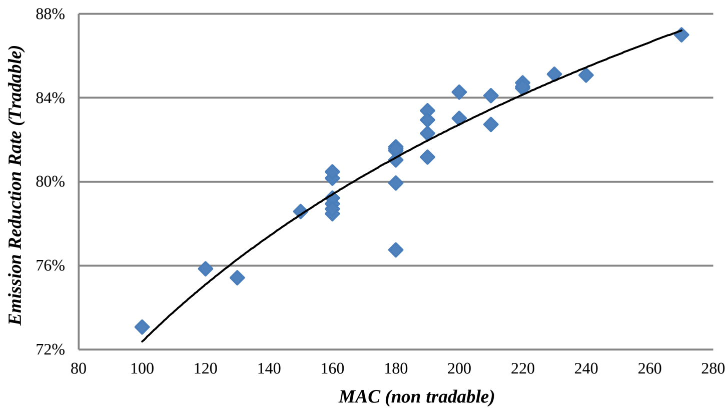

Fig. 10: Correlation between MAC and Emission Level

Comparing the scenarios with and without emission trading scheme (Fig. 11), 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. 11, emission trading scheme could recover output loss by 1.63%, and welfare loss by 0.43% under BMK emission allocation criterion; under BMK output criterion, output loss would be recovered by 3.71% and welfare loss by 34.23%; under BMK welfare criterion, output loss would be recovered by 11.44% and welfare loss by 43.15%.

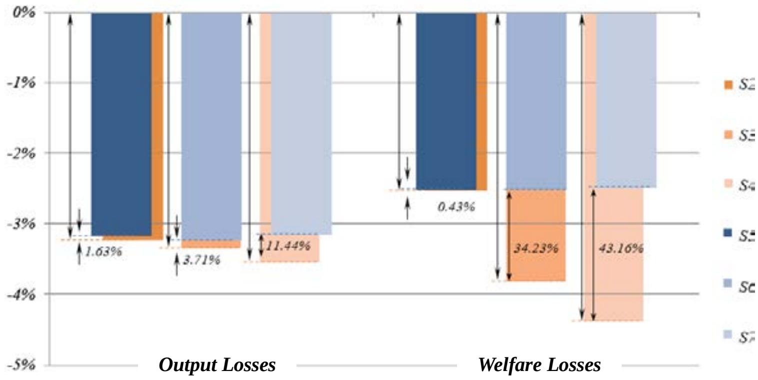

Fig. 11: Output and Welfare Effects of 20% Emission Reduction with and without Emission Trading

Fig. 11 also revealed the wide gap in economic and welfare effects of alternative permits allocation criterions when emission trading is not permitted. The highest output loss in BMK welfare criterion (*S4*) is 5.66% higher than the lowest in BMK emission criterion (*S2*), and the highest welfare loss is 76.38% 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.

4.5. Allocation of emission permits and inter-regional equity

As mentioned above, economic efficiency and inter-regional equity can be harmonized given emission trading scheme. And thus, we can simulate a certain allocation of emission permits under which welfare losses (in percentage) across regions are equalized. We explored this allocation criterion by external iteration, and the solution is shown in fig. 12, from which we can find that regions with high share of energy industry, high self-reliance of energy and energy intensive products or high MAC (e.g. Inner-Mongolia, Zhejiang, Gansu, etc) need to be provided with more permits since their welfare are more sensitive to emission reduction policies, and excessive permits could serve as cross-subsidy transferred from eastern industrialized regions. Given this allocation, economic output would decrease by 3.32% and welfare would decrease by 2.59% -- the economic efficiency has not been significantly affected by the reallocation of permits.

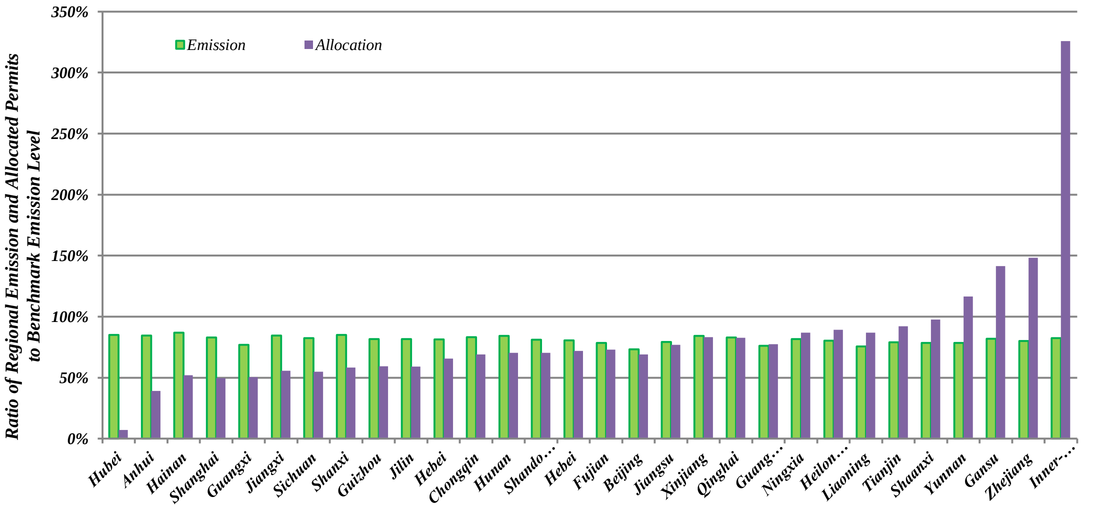

Fig. 12: Regional Emission and Allocation of Permits under Welfare-Loss Equalized Scenario (S8)

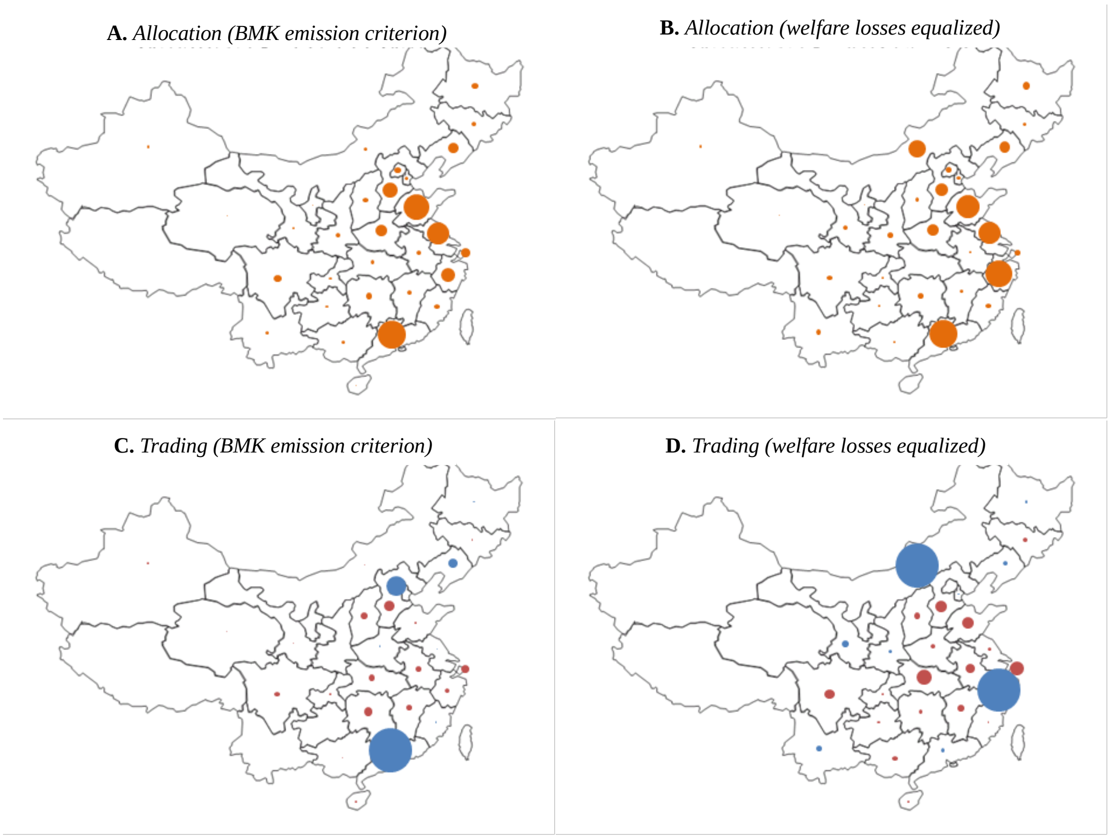

Fig. 13: Map for Emission Permits Allocation and Trade

Red dots in chart C & D stands for buying permits, while blue dots for selling.

Fig. 13 mapped the allocation of emission permits and the emission trading. Comparing chart A and B, we can find that the allocation of emission permits were concentrated in the eastern China and southeast coastal areas where higher levels of economic development. This is in line with the regional distribution of energy consumption in China. Under BMK emission criterion, regions with low MAC or low self-reliance of energy and energy intensive products, including Guangdong, Tianjin, Liaoning, etc. tend to sell their permits to the

Midwest areas with high MAC (as shown in chart C of fig. 13). Under equalized welfare loss criterion, regions including Inner-Mongolia, Zhejiang, Gansu, etc. are allocated with more permits since their welfare are more sensitive to emission reduction policies; while developed east coastal regions have to purchase emission permits from those regions, which transfers income from eastern regions to the aforementioned provinces (as shown in chart D in fig. 13).

5. Sensitivity Analysis for Factor Flow

Generally speaking, inter-regional flow of factors is meaningful for a multi-regional macroeconomic model, since change in factor input costs in a certain region would cause spread in prices across regions, lead to inter-regional flow of factor, and thus to alter regional supply of factors. Unfortunately, there are no statistics readily available for analysis of inter-regional factor flow, which hindered us in modeling factor flow. For logical completeness, we need to evaluate the importance of factor flow in our model, so as to prove the robustness of our simulation results.

In our paper, we estimated the impact of emission reduction on macroeconomic performances through adjusting input cost of energy. The sensitivity of demand for capital or labor to change in energy prices is mainly determined by substitutability between energy and capital or labor.

Berndt & Wood (1975) found complementarity between capital and energy, while labor is substitutable for energy. However, Griffin & Gregory (1976) protested the opposite conclusion. Pindyck & Rotemberg (1983) found that complementarity between energy or capital in short run, and it would switch to substitutability in long run. Zheng & Liu (2004) and Wu (2011) pointed out that the substitutability between energy and capital or labor in China is much smaller than that between capital and labor, in other words, change in energy price would not affect demand for capital and labor significantly. We carried a sensitivity analysis in our model to test the significance of factor flow to climate policy effects by setting capital and labor perfectly fluid across regions, and table 6 shows the result. From the table, we can find that altering the setting for factor flow does not affect the simulation results significantly.

Table 6: Sensitivity Analysis for Factor Flow

Scenario	*Carbon Tax Rate*	*Emission*			*Output*			*Welfare*		
		flowable	*Non-flowable*	*divergence*	*flowable*	*Non-flowable*	*divergence*	*flowable*	*Non-flowable*	*divergence*
S1	150	0.814	0.815	-0.16%	0.971	0.971	-0.01%	0.977	0.977	-0.04%
	175	0.789	0.791	-0.20%	0.966	0.967	-0.02%	0.972	0.973	-0.04%
	200	0.767	0.769	-0.21%	0.962	0.963	-0.01%	0.968	0.968	-0.05%
S2	150	0.814	0.815	-0.16%	0.971	0.97	0.04%	0.977	0.977	-0.02%
	175	0.789	0.791	-0.20%	0.966	0.966	0.04%	0.972	0.972	-0.03%
	200	0.767	0.769	-0.21%	0.962	0.962	0.05%	0.967	0.968	-0.03%
S3	150	0.876	0.875	0.16%	0.983	0.979	0.40%	0.98	0.978	0.18%
	175	0.856	0.854	0.19%	0.98	0.976	0.41%	0.975	0.973	0.19%
	200	0.836	0.834	0.24%	0.976	0.972	0.43%	0.971	0.969	0.20%

S4	150	0.88	0.879	0.19%	0.981	0.979	0.28%	0.977	0.975	0.13%
	175	0.862	0.861	0.19%	0.978	0.976	0.27%	0.972	0.971	0.13%
	200	0.844	0.843	0.16%	0.975	0.972	0.28%	0.968	0.967	0.13%
S5	150	0.814	0.815	-0.16%	0.971	0.971	-0.01%	0.977	0.977	-0.04%
	175	0.789	0.791	-0.20%	0.966	0.967	-0.01%	0.972	0.973	-0.04%
	200	0.767	0.769	-0.21%	0.962	0.962	0.00%	0.968	0.968	-0.04%
S6	150	0.814	0.815	-0.18%	0.97	0.97	0.01%	0.977	0.978	-0.02%
	175	0.789	0.791	-0.22%	0.966	0.966	0.01%	0.973	0.973	-0.03%
	200	0.767	0.769	-0.24%	0.962	0.962	0.02%	0.968	0.968	-0.03%
S7	150	0.814	0.815	-0.18%	0.971	0.971	-0.04%	0.977	0.978	-0.03%
	175	0.789	0.791	-0.22%	0.966	0.967	-0.04%	0.973	0.973	-0.04%
	200	0.767	0.769	-0.24%	0.962	0.963	-0.05%	0.969	0.969	-0.05%
Largest divergence				***0.24%***			***0.43%***			***0.20%***

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 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.

Under carbon taxation, the marginal abatement costs for 20% emission reduction is about 165 Yuan/t CO_2 in China, and would lead to 3.18% loss in total output for China, and 2.54% welfare loss.

Under mandatory regional emission constraints, economic and welfare effects of emission reduction are sensitive to allocation of emission permits. For 20% emission reduction, when the non-tradable permits are allocated across regions according to benchmark regional emission level, the losses in total output and welfare of China would be 3.24% and 2.58% respectively; when the permits are allocated according to benchmark regional output, the output and welfare losses would be 3.36% and 3.82% respectively; and when the permits are allocated according to benchmark regional welfare level, the output and welfare losses would be as high as 3.56% and 4.48%.

Comparatively, the output and welfare losses under Cap-and-Trade scenarios are significantly lower than in mandatory emission constraint scenarios. For 20% emission reduction, the total output and welfare losses would converge to about 3.2% and 2.5%, 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 last scenario modeled the allocation of emission permits which equalizes the welfare losses of emission reduction across regions. The model result indicated that in order to equalize welfare losses across regions, regions with high share of energy industry, high self-reliance of energy and energy intensive products or high MAC, e.g. Inner-Mongolia, Zhejiang, Gansu, etc. need to be assigned with more permits so that excessive permits could serve as cross-subsidy transferred from eastern industrialized regions. The output and welfare losses for 20% of emission reduction would be 3.32% and 2.59% in this scenario.

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:

$$A_{ij}^{g} = \phi\left(A_{iO}^{g}\right)^{\beta_1}\left(A_{Oj}^{g}\right)^{\beta_2}\frac{\left(G_i\right)^{\beta_3}\left(G_j\right)^{\beta_4}}{\left(D_{ij}\right)^{\beta_5}} \quad \text{……Eq. 3}$$

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*.[3]

According to the gravity model, we can make the original trade matrix for each commodity g as $\{\overline{a}_{ij}^{g}\}$, 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 $\{a_{ij}^{g}\}$:

$$\min\left(\sum_i\sum_j a_{ij}\ln\left(a_{ij}/\overline{a}_{ij}\right)\right), \text{ s.t.: } \sum_j a_{ij}^{g} * IF_i^{g} = OF_j^{g}, \sum_i a_{ij}^{g} = 1, 0 \le a_{ij}^{g} \le 1 \text{…Eq. 4}$$

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.

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[3] 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.

However, the 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}		