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Equity and Emissions Trading in China

Da Zhang[*†], Marco Springmann[‡§], and Valerie Karplus[†]

Abstract

China has embarked on an ambitious pathway for establishing a national carbon market in the next five to ten years. In this study, we analyze the distributional aspects of a Chinese emissions-trading scheme from ethical, economic, and stated-preference perspectives. We focus on the role of emissions permit allocation and first show how specific equity principles can be incorporated into the design of potential allocation schemes. We then assess the economic and distributional impacts of those allocation schemes using a computable general equilibrium model with regional detail for the Chinese economy. Finally, we conduct a survey among Chinese climate-policy experts on the basis of the simulated model impacts. The survey participants indicate a relative preference for allocation schemes that put less emissions-reduction burden on the western provinces, a medium burden on the central provinces, and a high burden on the eastern provinces. Most participants show strong support for allocating emissions permits based on consumption-based emissions responsibilities.

Contents

1. INTRODUCTION

Reducing the anthropogenic emissions of greenhouse gases (GHGs) linked to climate change is a major challenge for international governance. China surpassed the United States in 2007 to become the world's largest emitter of carbon dioxide (CO_2) (IEA, 2007; MNP, 2007) and has faced increasing international pressure to adopt stringent emissions-reduction commitments. In international negotiations China has pledged to reduce its carbon intensity, i.e. CO_2 emissions per unit of gross domestic product (GDP) by 40% to 45% from 2005 levels by 2020 (NRDC, 2009).

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Mitigation of global climate change poses a classic collective action problem (Olson, 1971). The potency of international action depends on how the benefits and costs of national participation are distributed both across countries as well as within their own borders. Identifying arrangements that are widely perceived as equitable and cost effective can help to overcome collective action barriers. In large and diverse countries such as China the subnational distribution of costs and impacts may play a major role in determining the acceptability of national climate policy commitments. Basing the allocation of cost burden on well-accepted equity principles can enhance legitimacy and achieve the level of agreement needed to adopt policy, assuming agreement can be reached on the principles to be applied. Focusing on China as a case study, we evaluate the implications of using common equity principles to distribute the costs of an emissions trading system (ETS), and then empirically assess which approach is most acceptable to experts engaged in policy design.

China's Twelfth Five-Year Plan for economic and social development (2011–2015) has integrated part of its international commitment into binding national policy. It sets forth the aim to reduce China's carbon intensity by 17% from 2011 to 2015 and lays out plans to gradually develop a carbon trading market. In 2011, the National Development and Reform Commission of China initiated the development of seven regional carbon trading pilots in five cities (Beijing, Tianjin, Shanghai, Chongqing, Shenzhen) and two provinces (Guangdong, Hubei). The pilots are expected to become operational in 2013 and inform the design of a national ETS to be announced in China's Thirteenth Five-Year Plan (2016–2020).

An ETS has several well-studied advantages over a regional allocation of emissions targets. First, an ETS attains cost efficiency by incentivizing emissions reductions where they are cheapest. By contrast, regionally constrained emissions limits reduce abatement flexibility, leading to equal or greater welfare losses (see, e.g., Tietenberg, 2006; and Zhang et al., 2013, for an application to the Chinese context). Second, an ETS attains cost-efficiency irrespective of the initial allocation of emissions permits (Coase, 1960; Montgomery, 1972; Rose and Tietenberg, 1993). Thus, efficiency and distributional (equity) objectives can be addressed separately in an ETS. The trade in emissions permits allows emissions to be reduced at least cost, while the initial allocation of emissions permits determines the regional distribution of this cost burden.

Distributional issues have been a major concern for China's policymakers in recent years. Pronounced differences exist between the developed eastern coastal provinces and the less developed central and western provinces (Keidel, 2007; Feng et al., 2009). Regional inequality has been rising since the late 1980s (Kanbur and Zhang, 2005) with only modest signs of decline (Zhang and Zou, 2012). Currently, the per capita GDP in the inland regions is less than half of that in the coastal regions on aggregate (Fan et al., 2011) and the differences between individual provinces and municipalities can reach up to a factor of ten (National Statistics Bureau of China, 2008).

To a large extent, preferential policy treatment of coastal regions during China's reform period in the late 1970s explains the existing regional economic differences (Démurger et al., 2002). However, more recent regional development strategies in the 1990s and 2000s, such as the "western development strategy" and the "rise of central China strategy" have put increased focus on reducing regional disparities (Chen and Zheng, 2008). The importance of promoting a more balanced regional development has continued to feature prominently in the Eleventh and Twelfth Five-Year Plans for economic and social development (2006–2010; 2011–2015).

In this study, we analyze the distributional aspects that are inherent in the design of a national emissions trading system. We focus on the different design options for allocating emissions permits to China's provinces and the potential economic impacts that result. Opting for a specific allocation of emissions permits offers a means of balancing the regional economic impacts of an ETS and at the same time addressing issues of equity and distributional justice inherent in environmental policymaking (Grubb et al. 1992, Kverndokk, 1995).

This study takes a three-part approach to analyze the distributional aspects of a national ETS in China. First, we construct a range of permit allocation schemes based on underlying ethical frameworks. This part builds on earlier studies on the international burden sharing of emissions reductions (see, e.g., Ringius et al., 2002; Kverndokk and Rose, 2008), but adapts the concepts discussed on the international level for the Chinese context.

Second, we analyze the potential economic impacts of different permit allocation schemes by using an interregional energy–economic model of the Chinese economy that separately represents the nation's 30 provinces. This part builds on an earlier assessment of a future ETS in China (Zhang et al., 2013) by explicitly considering different permit allocation schemes. By simulating the regional economic impacts of different allocation schemes in a future ETS, we also go beyond earlier studies which focused on the regional allocation of emissions-intensity reductions among China's provinces without considering their economic impacts or interactions within an ETS (Wei et al., 2011; Yi et al., 2011).

Third, we juxtapose the simulation results with insights based on an ETS survey conducted among Chinese research teams working on domestic climate policy analysis in China. The survey is intended to scope the views on the interregional distribution of burden in a future ETS in China and elicit the preferences for the specific permit allocation schemes analyzed in this study. The survey differs from one on the ethical preferences for different burden-sharing schemes conducted on the international level (Lange et al., 2007, 2010) due to its regional focus, intended use (informal versus econometrical), and consideration of a greater number of allocation schemes. The three parts of the analysis are described below, followed by an integrated discussion of its implications.

2. PERMIT ALLOCATION AND EQUITY CRITERIA

Equity considerations are implicit in any approach aimed at distributing the burden of climate change (or the entitlement to emit). They indicate what a person perceives as fair or just (normative perspective). They are also frequently used in international negotiations on climate change (positive perspective), in the form of "common but differentiated responsibilities" laid out by the United Nations Framework Convention on Climate Change (United Nations, 1992, Art.3.1), or the polluter-pays principle endorsed by the Organisation for Economic Co-Operation and Development (OECD, 1972, 1989).

There exist various categorizations of equity principles. For example, Rose et al. (1998) and Kverndokk and Rose (2008) group equity principles into allocation-based, outcome-based, and process-based. This study focusses on allocation-based and outcome-based approaches which inform the initial and final allocation of emissions permits, respectively. **Table 1** provides an overview of the equity criteria selected for this study. Most of the criteria selected have become canonical (see Kverndokk and Rose, 2008, for a detailed review)—including the principles of sovereignty, egalitarian, polluter pays, ability to pay, horizontal, and vertical.

We supplement the canonical equity criteria by three other criteria which are relevant for the Chinese context. We consider two criteria based on emissions intensity, the environmental reward and environmental subsidy criteria (see, e.g., Eyckmans and Finus, 2004), to capture China's focus on emissions intensity as a policy target. We also add a consumer-pays criterion to account for the significant regional separation that exists within China between production and consumption activities and their associated CO_2 emissions (Meng et al., 2011; Guo et al., 2012; Springmann et al., 2013; Feng et al., 2013).

In the following, we will focus on specific allocation schemes emerging from the different equity principles. In order to use an equity principle to allocate emissions permits, one has to specify its reference base. A reference base, such as emissions or population, transforms an equity principle into an operational rule, but has no ethical content by itself (Rose and Stevens, 1998). The reference bases applied to the equity criteria selected in this study are emissions (territorial and consumption-based), GDP, emissions intensity (i.e. emissions per unit of GDP), and population.

Table 1. Overview of various equity criteria, their definition, potential references bases, and the operational rules that follow. Scenario abbreviations are listed for further reference in the model and results sections. For detailed discussions on the equity criteria, see e.g., Rose et al (1998), Kverndokk and Rose (2008), Ringius et al. (2002), and Eyckmans and Finus (2004).

Criterion	Basic definition	Reference base	Operational rule	Scenario
		Allocation-Based		
Sovereignty	All regions have an equal right to pollute and to be protected from pollution.	territorial emissions	Distribute permits in proportion to emissions.	SOV
Polluter pays	The producers of goods should be held responsible for the pollution generated in the process.	territorial emissions	Distribute permits inversely to emissions.	PPP
Consumer pays	The consumer of goods should be held responsible for the pollution generated in the process.	consumptio n-based emissions	Distribute permits inversely to emissions.	CPP
Egalitarian	All people have an equal right to pollute and to be protected from pollution.	population	Distribute permits in proportion to population.	EGA
Ability to pay	Greater burden should be shouldered by those with higher economic resources.	inverse GDP	Distribute permits inversely to per capita GDP.	ABT
Environmental reward	Greater burden should be shouldered by those with higher potential for reducing emissions.	inverse emissions intensity	Distribute permits inversely to emissions intensity.	ERE
Environmental subsidy	The regions with the greatest potential for reducing emissions should be supported.	emissions intensity	Distribute permits in proportion to emissions intensity.	ESU
		Outcome-Based		
Horizontal	Regions with similar economic circumstances should bear similar burden.	welfare	Equalize welfare changes across regions.	EQU
Vertical	Regions with higher per capita GDP should bear a greater burden.	welfare	Distribute net welfare losses in proportion to per capita GDP.	PRG

2.1 Database

For specifying the equity criteria, reference bases, and the associated allocation schemes for the Chinese context, we employ a comprehensive database of economic activity, energy use, and the associated CO_2 emissions for China's provinces compiled by Zhang et al. (2013). The data is based on China's national input–output table and the full set of China's provincial input–output tables published in 2007 (National Statistics Bureau of China, 2011). The provincial input–output data for China specifies benchmark economic accounts for 30 provinces in China (Tibet is not included due to a lack of data and the small scale of its economic activities). Energy use is based on the 2007 *China Energy Statistical Yearbook* and emissions totals are quantified using fuel-specific CO_2 emissions factors (National Statistics Bureau of China, 2008). Zhang et al. (2013) provide further details on the method used for balancing and combining the data sets.

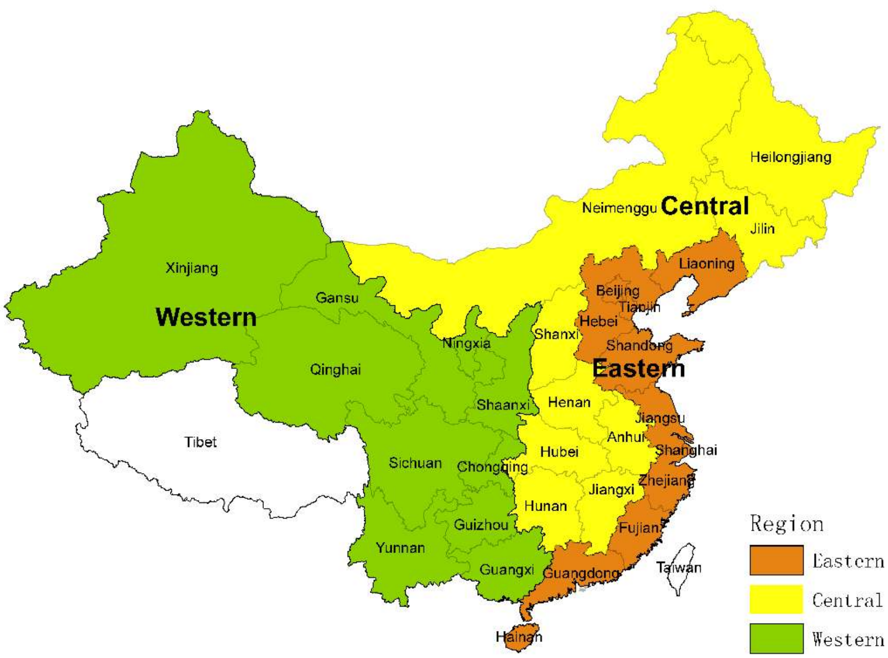

Figure 1. Overview of Chinese provinces included in the analysis.

Note: The eastern provinces include Beijing (BEJ), Fujian (FUJ), Guangdong (GUD), Hainan (HAI), Hebei (HEB), Jiangsu (JSU), Liaoning (LIA), Shandong (SHD), Shanghai (SHH), Tianjin (TAJ), and Zhejiang (ZHJ); the central provinces include Anhui (ANH), Heilongjiang (HLJ), Henan (HEN), Hunan (HUN), Hubei (HUB), Jiangxi (JXI), Jilin (JIL), Neimenggu (NMG), and Shanxi (SHX); the western provinces include Chongqing (CHQ), Gansu (GAN), Guangxi (GXI), Guizhou (GZH), Ningxia (NXA), Qinghai (QIH), Shaanxi (SHA), Sichuan (SIC), Xinjiang (XIN), and Yunnan (YUN).

For ease of presentation, we group China's provinces into eastern, central, and western ones according to the three economic zones defined in China's Seventh Five-Year Plan (State Council of China, 1986; Feng et al., 2012).[1] Figure 1 provides the details of this regional aggregation. The eastern provinces belong to the most economically developed areas with high levels of industrialization and rapid growth in international trade. The central provinces are less developed than the eastern provinces, but they have well-established infrastructures and abundant natural resources, such as coal, oil, and metal ores. The western provinces are the least developed ones, but they possess abundant coal, oil and natural gas reserves.

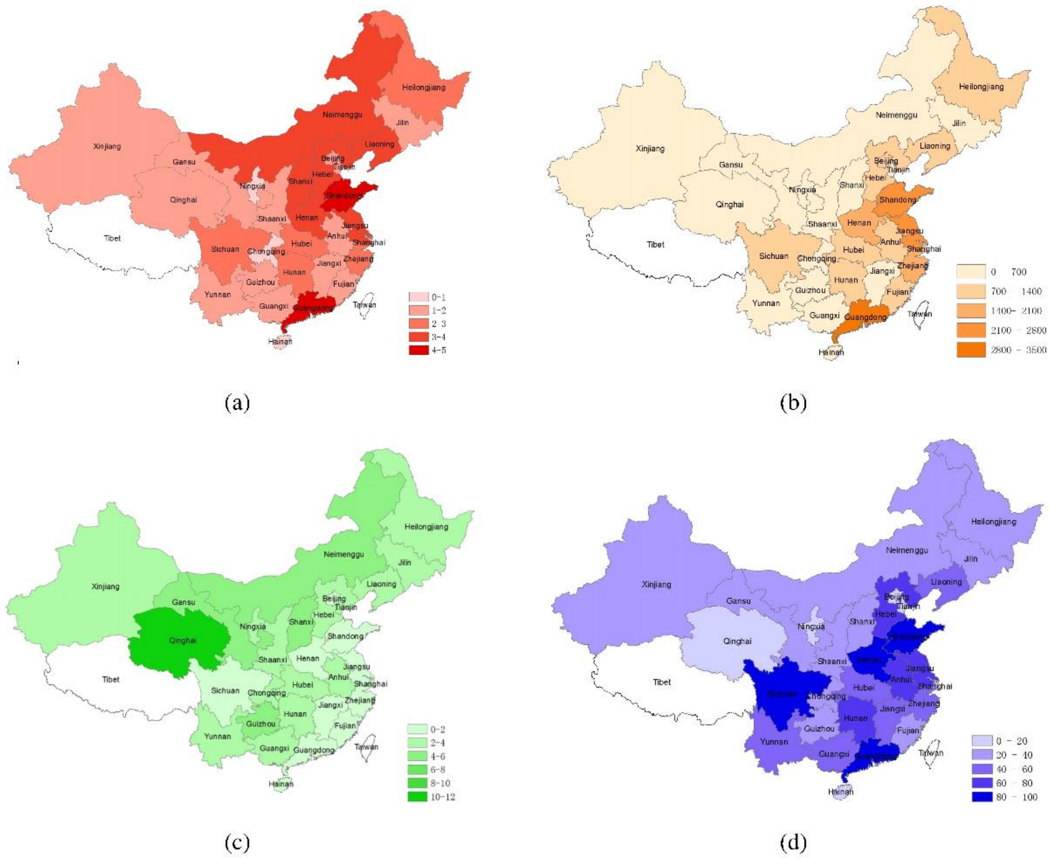

Figure 2. Regional distribution of (a) CO_2 emission (100 million tons), (b) GDP (billion Yuan), (c) CO_2 emission intensity (ton/10,000 Yuan), and (d) population (million) across China's provinces in 2007. Tibet is not included due to data availability.

Figure 2 shows the regional distribution of the indicators used as reference bases for this study's allocation schemes (CO_2 emissions, GDP, emissions intensity, and population). In general, population, economic activity, and CO_2 emissions are most concentrated in the eastern provinces, less concentrated in the central provinces, and least concentrated in the western

[1] Following Feng et al. (2012), we group Guangxi as a western province due to its economic similarities with western provinces. Although Inner Mongolia is sometimes also grouped as a western province, we group it as a central province, which is in line with its economic characteristics and with the grouping described by the State Council of China (1986).

provinces. Consumption-based emissions exacerbate that trend, because the eastern provinces consume more goods and associated CO_2 emissions than they produce (see Figure A1 in the appendix). The distribution of emissions intensity shows an opposite trend, i.e. lower emissions intensity in the eastern provinces and higher emissions intensity in the central and western provinces, which reflects differences in technological progress and industrial composition.

2.2 Permit Allocation across China's Provinces

We follow Rose et al. (1998) in their general methodology of mathematically specifying different permit-allocation schemes. To obtain the allocation of emissions permits for region *r* and allocation scenario *i* (E_r^i), we distribute a national emissions target ($\overline{CO_2}$) among Chinese provinces in proportion to their share with respect to the chosen reference base (b_r^i):

$$E_r^i = \frac{b_r^i}{\sum_s b_s^i} \overline{CO_2} \quad (1)$$

For example, the egalitarian scenario allocates emissions permits in proportion to a region's population divided by the total population and multiplied by the national emissions target. To specify the consumer-pays criterion, we calculate consumption-based emissions using a multiregional input–output approach that accounts for the emissions embodied in China's interregional trade (see Böhringer et al., 2011, and in particular Springmann et al., 2013).[2]

The basis for each allocation scenario is a stylized national emissions trading system in which the national emissions cap is set 17.7% below benchmark emissions. This emissions target results in emissions-intensity reductions of around 17%, the target of China's Twelfth Five-Year Plan (2011-2015). Although we adopt an emissions-intensity target consistent with China's Twelfth Five-Year Plan, our objective is not to simulate its future economic impacts. Instead our objective is to gain insights into the relative economic and distributional impacts of different approaches for allocating emissions permits.

We constrain the permit allocation such that no province can be allocated more than its baseline emissions. The purpose of this "stand-alone rule" (Lange et al., 2007) is to avoid undermining emissions-reduction efforts in overallocated provinces, which may be viewed as

[2] The outcome-based allocation scenarios (vertical and horizontal) depart from this methodology because they impose constraints on the outcome of economic model simulations. The horizontal EQU scenario equalizes the proportional welfare impacts across all provinces and the vertical PRG scenario distributes welfare losses in proportion to per capita GDP. The details of the economic model and the model simulations are described in Section 3.

unacceptable by constrained provinces.[3] A sensitivity analysis contained in Appendix A2 shows that without the constraint, the PPP, CPP, and ABT scenarios would allocate more emissions permits to the western provinces. The analysis indicates that this overallocation would result in disproportional wealth transfers (in terms of permit revenues) from the eastern provinces to the central and western ones, and in significant welfare losses for the eastern provinces.[4]

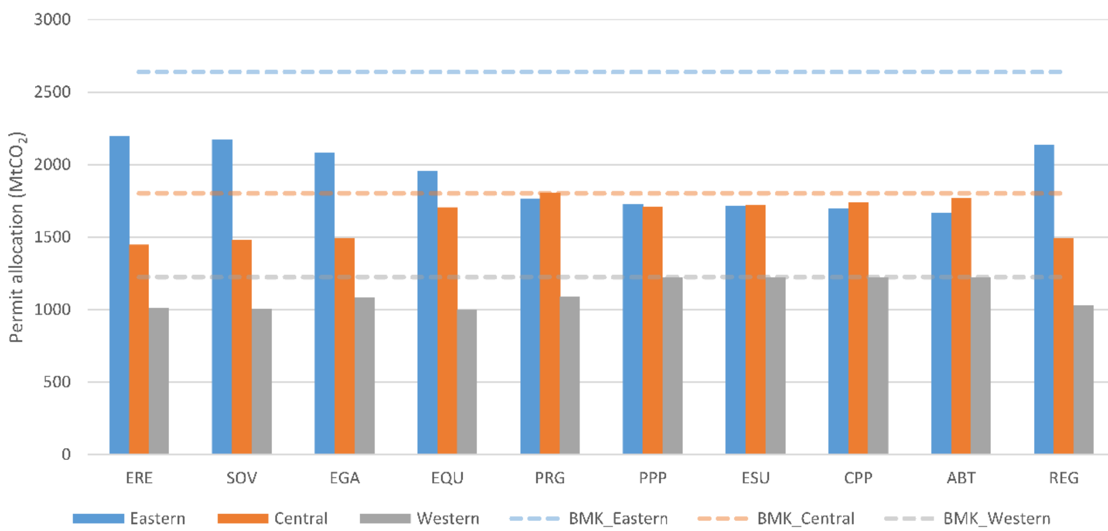

Figure 3. Regional permit allocation to China's eastern, central, and western provinces for the different allocation scenarios described in Table 1 and a REG scenario which represents the static emissions-reduction equivalent of the regional emissions-intensity targets of China's Twelfth Five-Year Plan. The dashed horizontal lines indicate the aggregated benchmark emissions for the eastern, central, and western provinces.

Figure 3 displays the regional allocation of emissions permits for the allocation scenarios considered. Table A2 in the appendix lists the permit allocation for each province. Several scenarios exhibit similar allocative characteristics (after each provinces' permit allocation has been constrained to not exceed its benchmark emissions). The ERE and SOV scenarios allocate most emissions permits to the eastern provinces because their allocation methods reward low emissions intensity (ERE) and high emissions (SOV). The central provinces are allocated about a third less emissions permits than the eastern provinces, and the western provinces about half. In

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[3] Allocated permits that would exceed the constraint are redistributed according to each scenario's allocation factor $(\frac{b_r^i}{\sum_s b_s^i})$ with the summation indices including the provinces among which the permits are to be redistributed. The redistribution procedure is carried out until no province is allocated permits in excess of its baseline emissions.

[4] An alternative approach to avoid overallocation would be to construct aggregate allocation scenarios as a combination of multiple allocation schemes. The sensitivity analysis contained in Appendix A2 shows that this could reduce the amount of overallocation, but it may still result in overallocation to individual provinces if the commonly suggested combinations of allocation schemes are used.

line with the allocation method of the SOV scenario, each province is allocated the same proportional 17.7% reduction of emissions permits compared to current benchmark emissions.

Going from the EGA scenario to the ABT scenario, fewer emissions permits are allocated to the eastern provinces and more to the central and western ones. The shift in permit allocation is small in the EGA scenario as the eastern provinces have a greater population on aggregate than the central and western ones. However, the proportional cutback between benchmark emissions and emissions-permit allocation for the eastern provinces increases to 33–35% in the PRG, PPP, ESU, CPP, and ABT scenarios. This is in line with the scenarios' allocation methods which allot more emissions permits to the provinces with low emissions (PPP), high emissions intensities (ESU), low consumption (CPP), and low per capita GDP (ABT, PRG), all of which are concentrated more in the center and west than in the east. As a result of the stand-alone rule, the PPP, ESU, CPP, and ABT scenarios allocate permits in proportion to benchmark emissions to many western provinces, while permit allocations in the PRG scenario approach benchmark levels in some central provinces.

In order to understand how the distributional impacts compare with current policy, we further compare the menu of allocation schemes described above to regional emissions-intensity targets of the Twelfth Five-Year Plan. The regional emissions-intensity targets of the Twelfth Five-Year Plan are differentiated by province (see Table A3 in the appendix). However, because their regional differentiation is modest, their static emissions-reduction equivalent (REG) is similar to the reduction of emissions permits with respect to benchmark emissions in the ERE, SOV, and EGA scenarios which feature similar proportional cutbacks in emissions permits for each region.[5]

3. ECONOMIC IMPACTS OF DIFFERENT PERMIT ALLOCATION

We now turn to simulate the economic and distributional effects of allocating emissions permits in a Chinese ETS according to the scenarios described above. For this analysis, we use an energy–economic model with regional detail for the Chinese economy (see Zhang et al., 2013). We provide a short model description followed by a discussion of the results.

3.1 Energy–Economic Model

The energy–economic model is a static multiregional multisector computable general equilibrium model based on optimizing behavior of economic agents. Consumers maximize welfare subject to budget constraints and producers combine intermediate inputs and primary

[5] We have calculated the static emissions-reduction equivalent of the REF scenario by using the energy–economic model as described in section 3.

factors at least cost to produce output. Energy resources are included as primary factors and their use is associated with the emission of carbon dioxide (CO_2). The production of energy and other goods is described by nested constant-elasticity-of-substitution (CES) production functions which specify the input composition and substitution possibilities among inputs. Inputs into production include labor, capital, natural resources (coal, natural gas, crude oil, and land), and intermediate inputs. Appendix A5 contains further details on the model's nesting structure. The model is formulated as a mixed complementarity problem (MCP) (Mathiesen, 1985; Rutherford, 1995) in which zero-profit and market-clearance conditions determine activity levels and prices.[6]

The model is calibrated to a comprehensive energy-economic data set which includes a consistent representation of energy markets in physical units, as well as detailed economic accounts for the year 2007. The data set is global, but includes regional detail for China's provinces. The global data comes from the database version 8 of the Global Trade Analysis Project (GTAP, Narayanan et al., 2012). Results for the rest of the world are aggregated at the level of three international regions (Europe, USA, and the rest of the world) to capture the international market impacts of distributional changes within China. The data for China is based on the country's national input–output table and the full set of provincial input–output tables published in 2007 (National Information Center of China, 2011) as described in Section 2. We resolve six energy sectors and 10 non-energy composites.[7] Elasticities of substitution are adopted from the GTAP 8 database, as well as from the MIT Emissions Prediction and Policy Analysis (EPPA) model (Paltsev et al., 2005).

Although we calibrate our energy-economic model to the latest available data, we note that the model results are best seen as illustrative of the general trends and relative trade-offs between the ETS allocation scenarios. In general, numerical results are influenced by the specific model setup and therefore subject to model and parameter uncertainty. In contrast, the relative changes across the different allocation scenarios can be seen as sufficiently robust (see Zhang et al., 2013, for a comprehensive sensitivity analysis on the effects of market distortions and parameter assumptions using the same energy-economic model applied here). Our choice of a static modeling framework increases the transparency of model impacts and avoids the uncertainties associated with future growth paths.

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[6] The model is formulated in the mathematical programming system MPSGE (Rutherford, 1999), a subsystem of GAMS, and solved by using PATH (Dirkse and Ferris, 1995).

[7] The energy goods include coal (COL), crude oil (CRU), refined-oil and coal products (OIL), natural gas (GAS), gas manufacture and distribution (GDT), and electricity (ELE); the non-energy sectors include agriculture (AGR), minerals mining (OMN), light industries (LID), energy-intensive industries (EID), transport equipment (TME), other manufacturing industries (OID), water (WTR), trade (TRD), transport (TRP), other service industry (OTH).

3.2 Permit Transfers and Welfare Impacts

In an ETS, the trade in emissions permits results in the equalization of marginal abatement costs across provinces leading to a cost-efficient distribution of emissions reductions. Of interest under each scenario is the final distribution of emissions reductions, the transfer of permits supporting this distribution, as well as the resulting changes in welfare levels for the different ETS allocation scenarios considered.

All national ETS scenarios result in a common cost-effective distribution of emissions reductions that can differ significantly from the initial distribution of emissions permits in each scenario. Although the absolute emissions reductions are similar for the eastern, central, and western provinces (about 330 $MtCO_2$ on average), the western provinces reduce emissions the most on a percentage basis—by 27% on aggregate—followed by the central and eastern provinces which reduce their emissions by 20% and 12%, respectively (see Table A4 in the appendix). Underlying this cost-effective distribution of emissions reductions are regional differences in marginal abatement costs, which are highest in the eastern provinces and lowest in the western ones—the distribution of emissions intensities is indicative of those differences (see Figure 2). The distribution of emissions reductions contrasts with the allocation of emissions permits. The differences are especially pronounced in the PPP, ESU, CPP, and ABT scenarios in which most of the western provinces are allocated their benchmark emissions and the eastern provinces are allocated 35% less permits than their benchmark emissions on aggregate.

Figure 4 shows the permit (and associated financial) transfers that occur to achieve the distribution of emissions reductions in each ETS scenario. The permit transfers emerge as the difference between the cost-efficient distribution of emissions reductions and the emissions permits allocated in each scenario. Provincial-level transfers are listed in Table A5 in the appendix. In each scenario, the eastern provinces are, on aggregate, net buyers of emissions permits, while the central and western provinces are net sellers. The permit and revenue transfers increase from about 130–160 $MtCO_2$ for USD 1.9–2.3 billion in the ERE and SOV scenarios to 560–660 $MtCO_2$ for USD 8.3–9.8 billion in the PRG, PPP, ESU, CPP, and ABT scenarios, which is in line with the reduction in the amount of emissions permits allocated to the eastern provinces in those scenarios.

Permit-transfer revenues are distributed according to the difference in permits allocated to the central and western provinces. The PPP, ESU, CPP, and ABT scenarios exhibit a roughly equal split of permit sales between the central and western provinces, which is in line with their similarity in absolute emissions reductions and close-to-benchmark permit allocation. In the EQU and PRG scenarios, proportionally more permits are allocated to the central provinces than to western ones, while proportionally more permits are allocated to the western provinces in the

ERE, SOV, and EGA scenarios. As a result, more permits are sold by the central provinces in the EQU and PRG scenarios, and more by the western provinces in the ERE, SOV, and EGA scenarios.

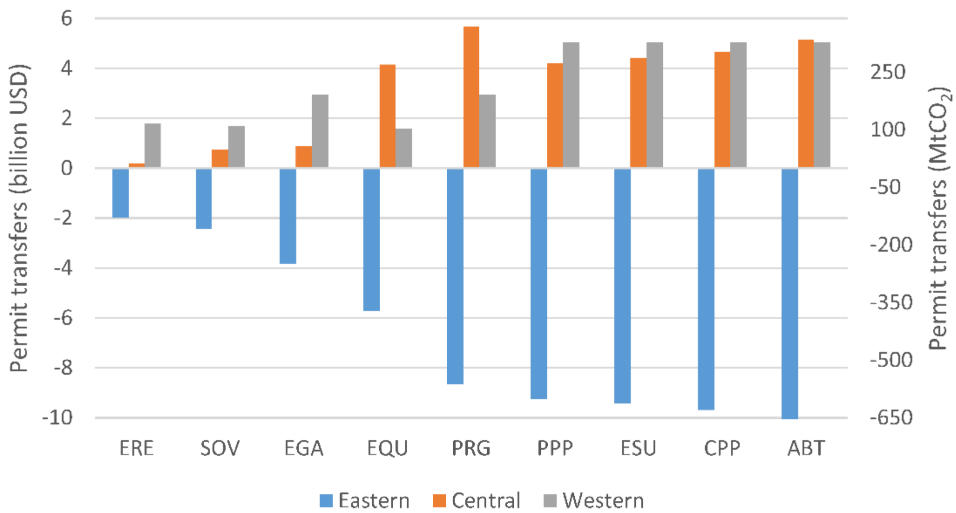

Figure 4. Regional distribution of permit transfers in in billion USD (left axis) and $MtCO_2$ (right axis).

Figure 5 shows the regional welfare impacts in terms of equivalent variation of income for the different ETS allocation scenarios. Provincial-level welfare impacts are listed in Table A6 in the appendix. Each ETS scenario results in a cost-efficient distribution of emissions reductions with the same national welfare impact. However, regional welfare impacts differ according to each province's permit allocation, marginal abatement costs, and transfer of permit revenues. As a consequence, the ERE, SOV, and EGA scenarios exhibit low welfare losses for the eastern provinces, but high losses for the central ones (as those are particularly reliant on fossil-fuel production), while the PRG, PPP, ESU, CPP, and ABT scenarios show low welfare losses or even gains for the western provinces, but greater losses for the eastern ones. By definition, the EQU scenario yields a proportionally equal burden for all provinces.

The impacts of the ETS allocation scenarios described above differ markedly from those of China's current policy approach of imposing regional CO_2 intensity targets without allowing for interprovincial trading. In Appendix A9, we compare the welfare impacts of those policy approaches and find that the non-tradable regional targets increase national welfare loss by 30%. The model results indicate that the central and western provinces would decrease their welfare losses in all allocation schemes when moving from the regional target allocation of China's Twelfth Five Year Plan to a national ETS. In contrast, the eastern provinces would decrease their welfare losses only in the ERE, SOV, and EGA scenarios, but their welfare decreases more in the

EQU, PRG, PPP, ESU, CPP, and ABT scenarios. The potentially negative consequences for the eastern provinces in the latter scenarios may hinder their adoption given the political influence of those provinces.

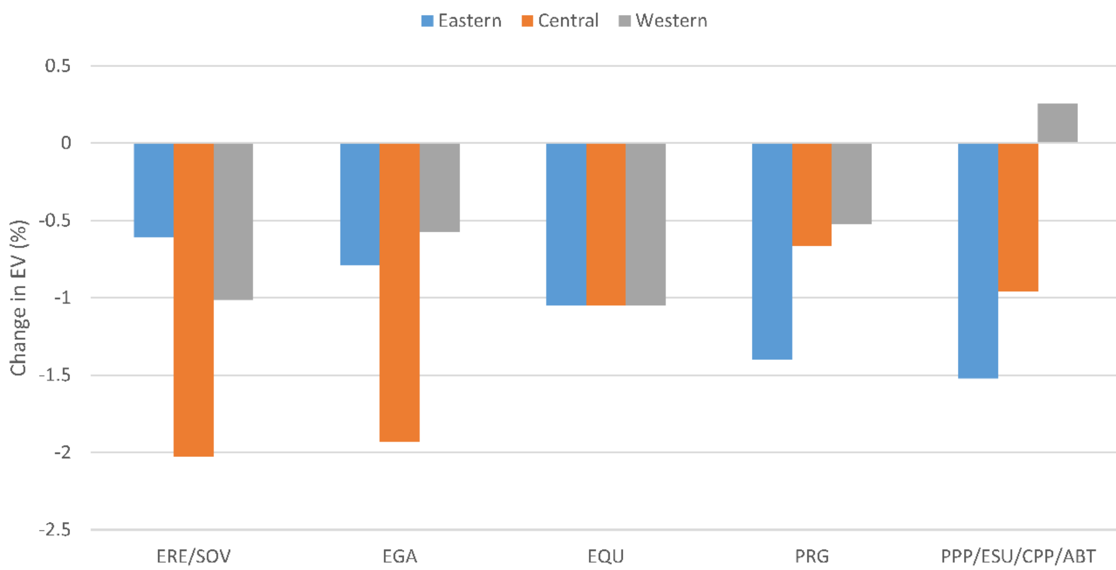

Figure 5. Regional distribution of welfare impacts in terms of equivalent variation of income (EV) for the different allocation scenarios. The ERE and SOV scenarios and the PPP, ESU, CPP, ABT are associated with similar welfare impacts; we group these scenarios together (by taking the average values) for ease of presentation. The figure serves as basis for the survey described in Section 4.

4. CHOOSING AMONG ALLOCATION SCHEMES

The preceding analysis provided an overview of the distribution of economic impacts under a wide range of allocation schemes applied to the Chinese context. Each allocation scheme is supported by a specific equity criterion and therefore justifiable from a particular ethical position. This complicates the selection and recommendation of a particular allocation rule to policymakers. Instead of assuming an equity rule that would be most compelling in China, we conducted a survey to scope the views on the different allocation schemes and, more generally, on the importance of the interregional distribution of burden in a future ETS in China.

4.1 Survey Overview

The survey was distributed among Chinese research groups involved in the analysis and design of climate policy in China. In general, input from expert research groups is very important in China's policy process (Cao, 2004; Meidan et al., 2009). In the process of establishing pilot emissions trading schemes as part of the Twelfth Five-Year Plan, the government regularly seeks input from research groups on the design of a future emissions trading system, and the policy advice provided to the government has, in many instances, been based on model assessments. We therefore focus on research groups with modeling capacity in national climate policies as target group for our survey.

The survey was distributed at two instances in June 2013 in China. The first instance was a CGE modeling workshop organized by the Center for Energy Economic and Strategy Studies (CEESS) of Fudan University, held on June 14–15, 2013, in Shanghai. The second was the Annual Stakeholders Meeting of the Tsinghua-MIT China Energy and Climate Project (CECP), held on June 18, 2013, in Beijing. Table A7 in the appendix contains a list of the institutional affiliations of the participating researchers. Before distributing the survey, we conducted two target-group assessments at an ETS workshop organized by the European Commission Directorate-General for Climate Action in Beijing on May 22, 2013, and at the Environment and Energy Track of the Shanghai Forum, which took place on May 25–27, 2013, in Shanghai. Based on those assessments, we are comfortable with the representation of relevant research teams in our focus group.

The questionnaire administered in the survey was structured into four parts. The first elicited the participants' general views on the importance of distributional issues (equity) and of efficiency. The second part asked the participants to distribute the burden of emissions reduction among China's regions (eastern, central, western) and express their opinion on different burden-sharing rules. The third part presented participants with the model outcomes discussed in the last section (Figure 5) and asked for their preferred outcome and unacceptable outcomes. The welfare impacts were first presented without scenario labels and then with scenario labels and brief descriptions of the equity criteria supporting each allocation scenario. The intention behind this two-stage approach was to elicit participants' distributional preferences with and without the ethical framing. The participants were given the option to change their preferences based on the information provided. Finally, the questionnaire asked for some background information, such as age, affiliation, and regions of origin and residence.

4.2 Survey Results

We received 44 responses. However, not all participants answered all questions, and as a result the number of responses differs across the questions. Table A8 in the appendix lists the participants' characteristics. Almost all respondents (41 out of 44; 93%) declare themselves as academics and about half of the respondents are below 30 years of age. Although three-fourths of the respondents now live in eastern China (77%), more than half of the respondents were born in central and western China (43% and 11%, respectively).

Table 2 summarizes the respondents' attitudes toward equity. Over 80% of the respondents declare that they are concerned with the way the economic burden of greenhouse gas reduction is distributed among China's provinces and more than half think that fairly distributing the burden of emissions reduction has the same importance as reducing emissions at least cost.

Table 2. Survey questions related to equity concerns and the trade-off between equity and efficiency.

Participants' attitudes toward equity	Frequency	Percent
How concerned you are with the way the economic burden of greenhouse gas reduction is distributed among China's provinces?		
Very concerned	24	54.55
Somewhat concerned	12	27.27
Neutral	6	13.64
Not very concerned	2	4.55
Not concerned at all	0	0
What is most important for you: a fair distribution of emissions reduction burden (equity), reducing emissions at least cost (efficiency), or both?		
Both are equally important.	24	54.55
Reducing emissions at least cost is more important.	12	27.27
A fair distribution of reduction burden is more important.	8	18.18

When prompted to distribute the burden of emissions reduction among China's regions, assuming that the distribution of burden does not increase overall costs, most respondents would put a medium-high to high burden on the eastern provinces (89%), a medium burden on the central provinces (66%), and a low to medium-low burden on the western provinces (75%). The associated distribution of frequencies is shown in **Figure 6**.

Figure 7 details the respondents' preferences for specific allocation schemes. When presented with the simulated welfare impacts of the specific unlabelled burden-sharing criteria considered in this study, 41% chose the progressive (PRG) scenario as their most preferred one, followed by the aggregate of polluter pays, consumer pays, ability to pay, and environmental subsidy (PPP/CPP/ABT/ESU) which was chosen by 27%; the egalitarian (EGA) scenario was chosen by the least (7%). When asked which of the different outcomes would be unacceptable (multiple choices were possible here), 57% of the respondents indicated that they would not be willing to accept the sovereignty and environmental reward (SOV/ERE) scenarios, 34% would not accept the equal impact (EQU) scenario, and 30% would not accept the egalitarian (EGA) scenario.

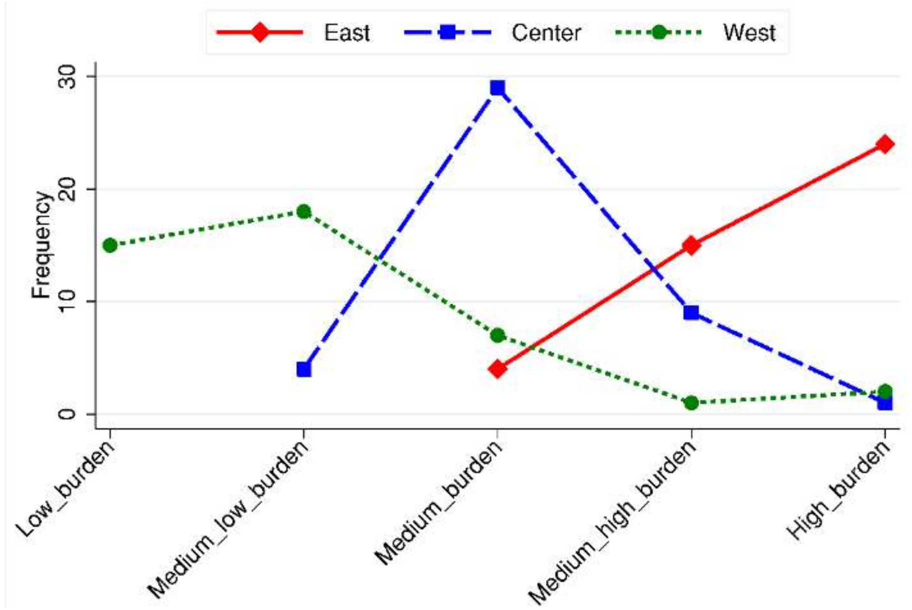

Figure 6. Respondents' preferences for the regional distribution of emissions-reduction burden among the eastern, central, and western provinces.

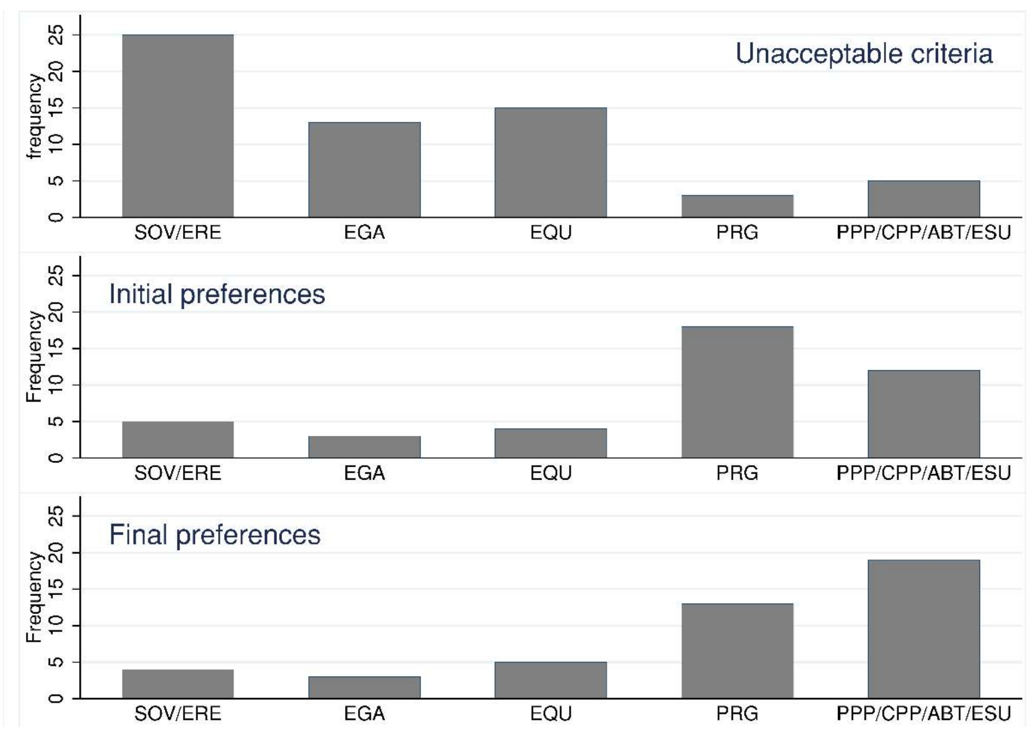

Figure 7. Respondents' preference for the specific allocation schemes considered in this study. The initial preferences followed the presentation of unlabeled welfare outcomes, the final preferences the presentation of labeled outcomes and scenario descriptions, and the unacceptable criteria indicate the schemes the respondents found unacceptable when first presented (with multiple choices possible).

When the burden-sharing scenarios were identified, a third of the respondents (32%) changed their preference, mostly from the PRG scenario to the PPP/CPP/ABT/ESU one. While most respondents did not provide a reason for that change, those who did noted that the aggregate PPP/CPP/ABT/ESU scenario is more comprehensive and that it considers both responsibility and capacity. The final distribution of preferences (depicted in Figure 7) shows that 43% would prefer the PPP/CPP/ABT/ESU scenario, 30% the PRG scenario, 11% the EQU scenario, 9% the SOV/ERE scenario, and 7% the EGA scenario.

Figure 8 reports the respondents' agreement with each of the burden-sharing criteria represented in the most preferred PPP/CPP/ABT/ESU scenario. When asked about their agreement on the individual burden-sharing criteria in the PPP/CPP/ABT/ESU group, the respondents indicated strongest agreement with the CPP criterion, followed by the PPP, ESU, and ABT scenarios (when first ranking the frequencies for "strongly agree" and then those for "somewhat agree").

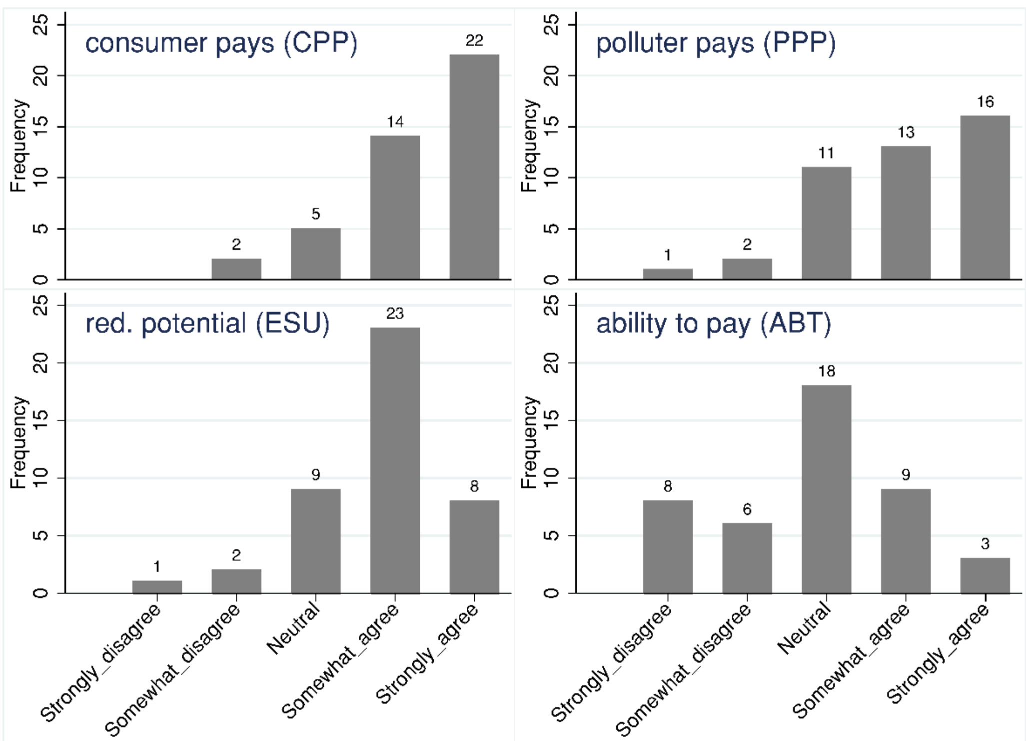

Figure 8. Respondents' agreement with the individual allocation schemes summarized in the PPP/ESU/CPP/ABT group (see Figure 5).

4.3. Discussion of Survey Results

The results of the survey provide insight into the relative merits of alternative burden-sharing scenarios according to scholars involved in China's climate policy design. Interestingly, we find that most favor a higher burden on the east and lower burden on the center and west. However, we also observe that the framing of the scenarios is important. The observed shift in participant preferences from PRG scenario to the PPP/CPP/ABT/ESU scenario after the corresponding equity principles are revealed supports this conclusion. Given emphasis in previous studies from scholars in China on creating combined equity indices, policy designs that address multiple criteria may turn out to be an important alternative to single-criteria designs. Multi-criteria designs may also attract the support of otherwise disparate vested policy interests that prefer a single equity criterion but are open to supporting designs reflecting other principles as well.

Given the highly differentiated impacts of the different allocation scenarios on China's regions, one could expect that the respondents' preferences are influenced by their region of origin or their residence.[8] However, our analysis, supported by detailed results shown in Appendix A12, does not provide strong support for that expectation. Although we find that most respondents living in central provinces prefer the PRG scenario which puts least burden on their provinces compared to other scenarios, a higher number of respondents living in the eastern provinces prefers the PPP/CPP/ABT/ESU scenario which puts the greatest burden on the eastern provinces. Reasons for the small effect of regional association may be the selection of respondents and the structure of environmental governance in China. Our target group was comprised of experts who provide regular input into the policymaking process. Traditionally, environmental (including climate) policy issues are often addressed at the central level in China, and balancing impacts across regions is often an important consideration. Thus, the experts in our target group may adopt a regionally more balanced view on distributional and efficiency issues than lay persons or representatives from affected industries.

There are several caveats to bear in mind when interpreting the survey results. First, we cannot rule out occasional misinterpretations of survey questions. Although the target group was comprised of experts, the abstract concepts related to equity and technical modeling results may have been confusing to some respondents. In particular the EQU (equal welfare losses imposed across all provinces) may not have been well understood by survey respondents, given that it is based on a theoretical construct and not on a tangible indicator or indicators, which have been used to guide the setting of China's energy and climate policy to date. We tried to address this point by proving explanatory paragraphs, bilingual questionnaires, and possibilities for personal feedback. Second, our target group consisted of climate-policy experts and therefore does not represent broader views on desirable distributional outcomes in China. In future studies, it would be interesting to explore how the views of experts compare with those held by policymakers, representatives of affected industries, or the views of the public at large. Finally, the survey's

[8] By "residence" we are referring to physical residence, not registered (hukou) residence.

regional aggregation into three broad regions may hide some regional differences and the respondents' interests in the impacts for specific provinces.

5. CONCLUSION

China has embarked on an ambitious pathway for establishing a national carbon market in the next five to ten years. In this study, we have analyzed the distributional aspects of a Chinese ETS from ethical, economic, and stated-preference perspectives. We have focused on the role of emissions permit allocation and showed that a wide range of potential allocation schemes exist, each supported by a specific equity principle. The economic analysis has shown that several allocation schemes exhibit similar distributional characteristics in terms of regional welfare impacts and flows of emissions permits when overallocation is ruled out.

A survey we conducted among climate-policy researchers in China has indicated a relative preference for those allocation schemes that put less emissions-reduction burden on the western provinces, a medium burden on the central provinces, and a high burden on the eastern provinces. When presented with the specific allocation schemes considered in this study, most respondents preferred the welfare outcome associated with the equity criteria of polluter pays, consumer pays, ability to pay, and ecological subsidy, noting that this combination of criteria is most comprehensive, while at the same time being in line with the respondents' general distributional preferences.

From a fiscal perspective, each allocation scheme would imply significant interregional transfers. In each allocation scheme, the eastern provinces are found to be net buyers of emissions permits, with permit payments to the western and central provinces ranging between USD 2–10 billion depending on the allocation scheme. In comparison, the annual equalization transfer, which was established by the Chinese government in 1995 to ease the widening regional disparities, amounted to about USD 9 billion (74.5 billion Yuan) in 2004 (Shen et al., 2012). The financial transfers associated with an ETS would therefore constitute a significant flow of interregional funds. An added benefit is that the market-based nature of those flows may make them more robust and predictable than budgetary government transfers which have been subject to fluctuation in the past (Shen et al., 2012). However, a market-based scheme also means that the magnitude of the interregional flows will be subject to fluctuations in the carbon price.

From a political perspective, adopting allocation schemes which generate large interregional transfers could be challenging. An analysis of the regional emissions-intensity targets of China's Twelfth Five-Year Plan has shown that the eastern provinces currently shoulder a relatively modest reduction burden compared to that of the central and western provinces (Springmann et al., 2013). An analysis in Appendix A9 indicates that the eastern provinces would experience a greater economic burden in the allocation scenarios which generate high interregional transfers, such as those preferred by most survey participants. The potentially negative consequences for the eastern provinces in those scenarios may hinder adoption given the political and economic influence that those provinces have. However, there may exist room for negotiation between the central government and the provinces on specific allocation schemes, as moving from regional targets to an ETS could significantly reduce welfare losses.

Although our analysis has focused on the Chinese context, its approach of studying the distributional impacts of regional emissions allocation within a national emissions-trading system has international implications. Balancing economic efficiency with distributional and equity concerns can be expected to play a key role in other emerging carbon markets, in particular in countries with large regional inequalities and uneven economic development, such Brazil, Chile, Turkey, Mexico, and the United States. By combining economic modeling with survey techniques, our study represents a more comprehensive analysis than those relying on one method alone. Such multi-method approaches may prove compelling as a way to identify consensus options in the policy design process.

Acknowledgments

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6. REFERENCES

Armington, P.S., 1969: A Theory of Demand for Products Distinguished by Place of Production. *International Monetary Fund Staff Papers*, 16(1): 159–176.

Böhringer, C., J.C. Carbone, and T.F. Rutherford, 2011: Embodied carbon tariffs. *NBER Working Paper No. 17376*, National Bureau of Economic Research, Cambridge, MA.

Cao, C., 2004: China's Scientific Elite. *Routledge Studies on China in Transition*, Book 21.

Chen, M., and Y. Zheng, 2008: China's regional disparity and its policy responses. *China & World Economy*, 16: 16–32.

Coase, R.H., 1960: The Problem of Social Cost. *Journal of Law and Economics*, 3: 1–30.

Démurger, S., J.D. Sachs, W.T. Woo, S. Bao, G. Chang, and A. Mellinger, 2002: Geography, Economic Policy, and Regional Development in China. *Asian Economic Papers*, 1: 146–197.

Dirkse, S.P., and M.C. Ferris, 1995: The PATH Solver: A Non-Monontone Stabilization Scheme for Mixed Complementarity Problems. *Optimization Methods and Software*, 5:123–156.

Eyckmans, J., and M. Finus, 2004: *An Empirical Assessment of Measures to Enhance the Success of Global Climate Treaties*. Katholieke Universiteit Leuven, Centrum voor Economische Studiën, Energy, Transport and Environment.

Fan, S., R. Kanbur, and X. Zhang, 2011: China's regional disparities: Experience and policy. *Review of Development Finance*, 1(1): 47–56.

Feng, K., S.J. Davis, L. Sun, X. Li, D. Guan, W. Liu, Z. Liu, and K. Hubacek, 2013: Outsourcing CO_2 within China. *Proceedings of the National Academy of Sciences (PNAS)* 110(28): 11654–11659.

Feng, K., Y.L. Siu, D. Guan, and Hubacek, 2012: Analyzing Drivers of Regional Carbon Dioxide Emissions for China. *Journal of Industrial Ecology*, 16(4): 600–611.

Feng, K., K. Hubacek, D. Guan, 2009: Lifestyles, technology and CO_2 emissions in China: A regional comparative analysis. *Ecological Economics*, 69(1): 145–154.

Grubb, M., J. Sebenius, A. Magalhaes, and S. Subak, 1992: Sharing the burden. *Confronting Climate Change: Risks, Implications and Responses*. Cambridge University Press, Cambridge, pp. 305–322.

Guo, J., Z. Zhang, and L. Meng, 2012: China's provincial CO_2 emissions embodied in international and interprovincial trade. *Energy Policy*, 42: 486–497.

International Energy Agency (IEA), 2007: World Energy Outlook 2007: China and India Insights. Paris, France (http://www.worldenergyoutlook.org/media/weowebsite/2008-1994/weo_2007.pdf).

Kanbur, R., and X. Zhang, 2005: Fifty Years of Regional Inequality in China: A Journey through Central Planning, Reform, and Openness. *Review of Development Economics*, 9(1): 87–106.

Keidel, A., 2007: China Regional Disparities—The Causes and Impact of Regional Inequalities in Income and Well-Being, Carnegie Endowment for International Peace (http://carnegieendowment.org/files/Keidel2.pdf).

Kverndokk, S. and A. Rose, 2008: Equity and justice in global warming. *Review of Environmental and Resource Economics*, 2(2): 135–176.

Kverndokk, S., 1995: Tradable CO_2 Emission Permits: Initial Distribution as a Justice Problem. *Environmental Values*, 4: 129–148.

Lange, A., A. Löschel, C. Vogt, and A. Ziegler, 2010: On the self-interested use of equity in international climate negotiations. *European Economic Review*, 54: 359–375.

Lange, A., C. Vogt, and A. Ziegler, 2007: On the Importance of Equity in International Climate Policy: An Empirical Analysis. *Energy Economics*, 29: 549–562.

Mathiesen, L., 1985: Computation of economic equilibria by a sequence of linear complementarity problems. *Economic equilibrium: model formulation and solution*, 23: 144–162.

Meidan, M, Andrews-Speed, P. and M. Xin, 2009: Shaping China's Energy Policy: actors and processes. *Journal of Contemporary China*, 18:61, 591-616.

Meng, L., J. Guo, J. Chai, and Z. Zhang, 2011: China's regional CO_2 emissions: Characteristics, inter-regional transfer and emission reduction policies. *Energy Policy*, 39(10): 6136–6144.

MNP (Netherlands Environmental Assessment Agency), 2007: China now no. 1 in CO_2 emissions; USA in second position. Accessed 29 October, 2012. (www.pbl.nl/en/dossiers/Climatechange/moreinfo/Chinanowno1inCO2emissionsUSAinsecondposition).

Montgomery, W.D., 1972: Markets in licenses and efficient pollution control programs. *Journal of Economic Theory*, 5: 395–418.

Narayanan, G., A.A. Badri, and R. McDougall, (eds.), 2012*: Global Trade, Assistance, and Production: The GTAP 8 Data Base*. Center for Global Trade Analysis, Purdue University.

National Statistics Bureau of China, 2008: *2007 China Energy Statistical Yearbook*. Beijing, China: National Statistical Bureau of China.

National Statistics Bureau of China, 2011: 2007 *China Regional Input-Output Tables*.

NRDC (National Resources Defense Council), 2009*: From Copenhagen accord to climate action: Tracking national commitments to curb global warming*. Accessed 29 October, 2012 (www.nrdc.org/international/copenhagenaccords/).

OECD (Organization of Economic Cooperation and Development), 1972: *Recommendation of the council on guiding principles concerning international economic aspects of environmental policies*. Council Document no. C(72)128, Organization of Economic Cooperation and Development: Paris, May.

OECD (Organization of Economic Cooperation and Development), 1989: *Recommendation of the Council concerning the Application of the Polluter- Pays Principle to Accidental Pollution C(89)88*. Organization of Economic Cooperation and Development: Paris.

Olson, M., 1971: *The Logic of Collective Action: Public Goods and the Theory of Groups* (Revised edition ed.). Harvard University Press.

Paltsev, S., J.M. Reilly, H.D. Jacoby, R.S. Eckaus, J. McFarland, M. Sarofim, M. Asadoorian, and M. Babiker, 2005: The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4. MIT JPSPGC *Report 125*, August, 72 p. (http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt125.pdf).

Peters, G.P., J.C. Minx, C.L. Weber, and O. Edenhofer, 2011: Growth in emission transfers via international trade from 1990 to 2008. *Proceedings of the National Academy of Sciences*, 108(21): 8903–8908.

Peters, G.P., and E.G. Hertwich, 2008: CO_2 embodied in international trade with implications for global climate policy. *Environmental Science & Technology*, 42(5): 1401–1407.

Ringius, L., A. Torvanger, and A. Underdal, 2002: Burden Sharing and Fairness in International Climate Policy. *International Environmental Agreements*, 2: 1–22.

Rose, A., B. Stevens, J. Edmonds, and M. Wise, 1998: International Equity and Differentiation in Global Warming Policy. *Environmental and Resource Economics*, 12(1): 25–51.

Rose, A., and B. Stevens, 1998: Will a Global Warming Agreement Be Fair to Developing Countries? *International Journal of Environment and Pollution*, 9(2/3): 157–178.

Rose, A., and T. Tietenberg, 1993: An international system of tradeable CO_2 entitlements: implications for economic development. *The Journal of Environment & Development*, 2(1): 1–36.

Rutherford, T.F., 1995: Extension of GAMS for complementarity problems arising in applied economic analysis. *Journal of Economic Dynamics and Control*, 19(8): 1299–1324.

Rutherford, T.F., 1999: Applied general equilibrium modeling with MPSGE as a GAMS subsystem: an overview of the modeling framework and syntax. *Computational Economics*, 14:1–46.

Shen, C., Jin, J. and H. Zou, 2012: Fiscal Decentralization in China: History, Impact, Challenges and Next Steps. *Annals of Economics and Finance*, 13-1, 1-51.

Springmann, M., D. Zhang, and V.J. Karplus, 2013: Consumption-Based Adjustment of China's Emissions-Intensity Targets: An Analysis of its Potential Economic Effects. MIT JPSPGC *Report 241*, March, 29 p. (http://globalchange.mit.edu/files/document/MITJPSPGC_Rprt241.pdf).

State Council of China, 1986: *The 7th Five Year Plan for National Economic and Social Development of the People's Republic of China, 1986–1990*. Beijing, China: State Council of China.

Tietenberg, T., 2006: *Emissions Trading: Principles and Practice*. Resources for the Future. RFF Press, 248 p.

United Nations, 1992: *United Nations Framework Convention on Climate Change (UNFCCC).* Rio de Janeiro, Brazil.

Wei, C., J. Ni, and L. Du, 2011: Regional allocation of carbon dioxide abatement in China. *China Economic Review*, 23(3): 552–565.

Yi, W.J., L.L. Zou, J. Guo, K. Wang, and Y.M. Wei, 2011: How can China reach its CO_2 intensity reduction targets by 2020? A regional allocation based on equity and development. *Energy Policy*, 39(5): 2407–2415.

Zhang, D., S. Rausch, V. Karplus, and X. Zhang, 2013: Quantifying regional economic impacts of CO_2 intensity targets in China. *Energy Economics*, 40: 687–701.

Zhang, Q., and H. Zou, 2012: Regional inequality in contemporary China. *Annals of Economics and Finance*, 13: 113–137.

APPENDIX

Contents

A1. CONSUMPTION-BASED EMISSIONS INVENTORIES

Consumption-based emissions inventories add to production-based emissions those emissions that are embodied in imports (e_r^{IM}), but subtract those emissions that are embodied in exports (e_r^{EX}):

$$e_r^{CON} = e_r^{PRD} + e_r^{IM} - e_r^{EX} = e_r^{PRD} + B_r \qquad (1)$$

where $B_r (= e_r^{IM} - e_r^{EX})$ denotes the balance of emissions embodied in trade (BEET) (see, e.g., Peters and Hertwich, 2008), also referred to as emissions transfer (Peters et al., 2011).

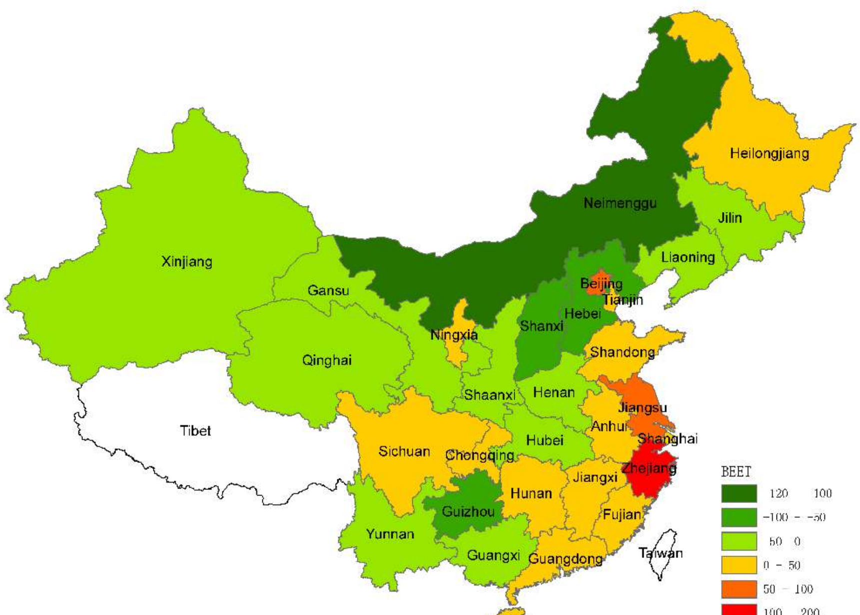

Figure A1. Balance of emissions embodied in trade (BEET) between China's provinces. Positive numbers indicate a greater share of emissions embodied in imports than those embodied in exports.

For obtaining the interregional emissions transfers we apply a recursive diagonalization algorithm as described in Böhringer et al. (2011). **Figure A.1** provides an overview of China's interregional emissions transfers (see Springmann et al., 2013 for a more detailed description). On net, the eastern provinces import about 350 MtCO_2 of embodied emissions, i.e. 14% of their territorial emissions. Sixty percent of those emissions (212 MtCO_2) are embodied in imports from the central provinces and 40% (136 MtCO_2) in imports from the western provinces. The percentage emissions transfers for individual regions can be much larger than the average. For example, the eastern provinces of Zhejiang, Hainan, and Beijing each import embodied emissions which amount to more than 70% of their territorial emissions. On the other hand, the central province of Inner Mongolia (Neimenggu) and the western province of Guizhou each export embodied emissions which amount to more than 40% of their territorial emissions.

A2. UNCONSTRAINED ALLOCATION SERIES

Table A1. Permit allocation, permit transfers, and welfare impacts for the unconstrained allocation scenarios and for an aggregate allocation scenario (AGG). The AGG scenario is loosely based on an aggregate index for regional target allocation constructed by Yi et al. (2011) which combines emissions (to indicate responsibility), inverse emissions intensities (to indicate potential), and inverse per capita emissions (to indicate capacity).

Allocation scenario	Permit allocation ($MtCO_2$)			Permit transfers (USD billion)			Change in EV (%)		
	Eastern	Central	Western	Eastern	Central	Western	Eastern	Central	Western
ERE	2386	1198	1075	0.85	-3.50	2.65	-0.238	-3.063	-0.629
SOV	2171	1482	1007	-2.33	0.70	1.64	-0.634	-1.953	-1.024
EQU	1954	1705	1000	-5.51	3.99	1.52	-1.051	-1.051	-1.051
EGA	1861	1590	1208	-6.93	2.31	4.62	-1.198	-1.561	0.151
PRG	1765	1805	1089	-8.31	5.47	2.84	-1.401	-0.664	-0.524
PPP	1745	928	1986	-8.62	-7.46	16.09	-1.568	-4.025	4.564
CPP	1315	1083	2261	-14.96	-5.17	20.13	-2.291	-3.435	6.151
ESU	1035	1335	2289	-19.06	-1.40	20.46	-2.806	-2.495	6.360
ABT	1014	818	2826	-19.32	-9.00	28.31	-2.910	-4.521	9.210
AGG	1837	1387	1436	-7.27	-0.70	7.98	-1.258	-2.315	1.485

A3. PERMIT ALLOCATION BY PROVINCE

Table A2. Permit allocation ($MtCO_2$) by province.

Region	ERE	SOV	EGA	EQU	PRG	PPP	ESU	CPP	ABT
ANH	179	147	179	149	168	179	179	179	179
BEJ	108	89	68	126	85	108	108	108	92
CHQ	118	97	117	127	134	118	118	118	118
FUJ	148	122	148	84	86	148	148	148	148
GAN	73	117	108	122	128	143	143	143	143
GUD	342	281	342	202	168	179	122	178	178
GXI	116	95	116	70	83	116	116	116	116
GZH	79	130	156	89	100	158	158	158	158
HAI	23	19	23	20	23	23	23	23	23
HEB	169	294	287	277	288	172	288	228	296
HEN	226	243	296	230	250	208	215	231	296
HLJ	173	142	158	212	218	173	173	173	173
HUB	206	170	207	93	107	207	207	207	207
HUN	187	154	187	170	187	187	187	187	187
JIL	137	144	113	133	140	175	175	175	175
JSU	358	302	315	231	207	167	136	149	150
JXI	112	92	112	86	96	112	112	112	112
LIA	178	228	178	239	240	221	273	247	224
NMG	113	206	100	252	251	245	250	250	219
NXA	32	26	25	29	31	32	32	32	32
QIH	41	69	23	65	66	83	83	83	83
SHA	114	94	114	150	159	114	114	114	114
SHD	277	345	388	314	311	146	176	148	208
SHH	199	164	77	120	57	199	172	199	85
SHX	115	183	140	381	387	222	222	222	222
SIC	190	157	190	159	181	190	190	190	190
TAJ	131	108	46	119	107	131	131	131	125
XIN	118	97	87	129	134	118	118	118	118
YUN	131	124	151	59	72	151	151	151	151
ZHJ	266	219	209	220	194	231	136	139	137
Eastern	2200	2171	2081	1954	1765	1727	1714	1698	1665
Central	1448	1482	1491	1705	1805	1709	1721	1737	1770
Western	1011	1007	1087	1000	1089	1224	1224	1224	1224

A4. EMISSIONS INTENSITY TARGETS OF CHINA'S TWELFTH FIVE-YEAR PLAN

Table A3. Emissions intensity targets of China's Twelfth Five-Year Plan by province.

Carbon intensity reduction target (%)	Provinces
19.5	Guangdong
19	Tianjin, Shanghai, Jiangsu, Zhejiang
18	Beijing, Hebei, Liaoning, Shandong
17.5	Fujian, Sichuan
17	Shanxi, Jilin, Anhui, Jiangxi, Henan, Hubei, Hunan, Chongqing, Shannxi
16.5	Yunnan
16	Neimenggu, Heilongjiang, Guangxi, Guizhou, Gansu, Ningxia
11	Hainan, Xinjiang,
10	Qinghai, Xizang

A5. DESCRIPTION OF THE ENERGY-ECONOMIC MODEL

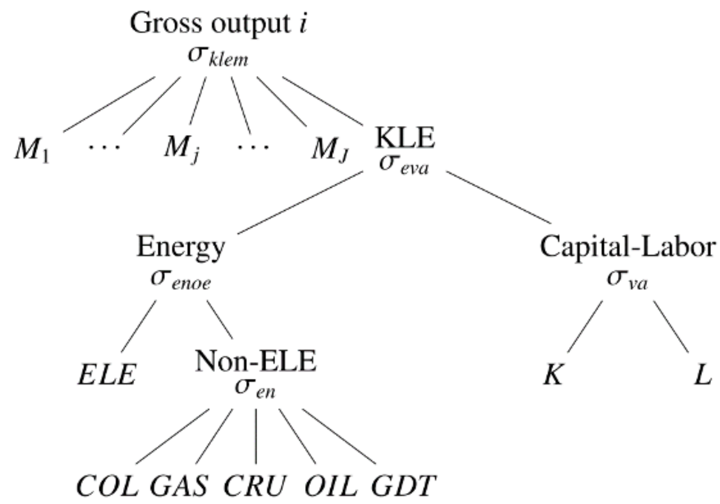

Figure A2. Nesting structure of CES production functions for non-energy goods.

The production of energy and other goods is described by nested constant-elasticity-of-substitution (CES) production functions which specify the input composition and substitution possibilities between inputs (see **Figure A2**). Inputs into production include labor, capital, natural resources (coal, natural gas, crude oil, and land), and intermediate inputs. For all non-energy goods, the CES production functions are arranged in four levels. The top-level nest combines an aggregate of capital, labor, and energy inputs (KLE) with material inputs (M); the second-level nest combines energy inputs (E) with a value-added composite of capital and labor inputs (VA) in the KLE-nest; the third-level nest captures the substitution possibilities between electricity (ELE) and final-energy inputs (FE) composed, in the fourth-level nest, of coal (COL), natural gas (GAS), gas manufacture and distribution (GDT), crude oil (CRU), and refined oil products (OIL).

The production of energy goods is separated into fossil fuels, oil refining and gas manufacture and distribution, and electricity production. The production of fossil fuels (COL, GAS, CRU) combines sector-specific fossil-fuel resources with a Leontief (fixed-proportion) aggregate of intermediate inputs, energy, and a composite of primary factors, described by a Cobb-Douglas function of capital, and labor. Oil refining (OIL) and gas manufacture and distribution (GDT) are described similarly to the production of other goods, but with a first-level Cobb-Douglas nest combining the associated fossil-fuel inputs (crude oil for oil refining; and coal, crude oil, and natural gas for gas manufacture and distribution) with material inputs and the capital-labor-energy (KLE) nest. Electricity production is described by a Leontief nest which combines, in fixed proportions, several generation technologies, including nuclear, hydro, and wind power, as well as conventional power generation based on fossil fuels. Non-fossil-fuel generation is described by a CES nest combining specific resources and a capital-labor aggregate.

All industries are characterized by constant returns to scale and are traded in perfectly competitive markets. Capital mobility is represented in each sector by following a putty-clay approach in which a fraction of previously installed capital becomes nonmalleable in each sector. The rest of the capital remains mobile and can be shifted to other sectors in response to price changes. The modeling of international trade follows the Armington (1969) approach of differentiating goods by country of origin. Thus, goods within a sector and region are represented as a CES aggregate of domestic goods and imported ones with associated transport services. Goods produced within China are assumed to be closer substitutes than goods from international sources to replicate a border effect.

Final consumption in each region is determined by a representative agent who maximizes consumptions subject to its budget constraint. Consumption is represented as a CES aggregate of non-energy goods and energy inputs and the budget constraint is determined by factor and tax incomes with fixed investment and public expenditure.

A6. EMISSIONS REDUCTIONS IN THE ETS ALLOCATION SCENARIOS

Table A4. Regional emissions reductions in the ETS allocation scenarios.

Region	Emissions Reduction	
	$MtCO_2$	**%**
Eastern	-311	-11.8%
Western	-366	20.3%
Central	-328	-26.8%
China	-1005	-17.7%

A7. PERMIT TRANSFERS BY PROVINCE

Table A5. Value of permit transfers (USD billion) by province. Negative numbers indicate payments and positive numbers indicate receipts.

Region	ERE	SOV	EGA	EQU	PRG	PPP	ESU	CPP	ABT
ANH	0.430	-0.038	0.430	-0.011	0.267	0.431	0.432	0.432	0.431
BEJ	0.220	-0.064	-0.383	0.487	-0.131	0.220	0.220	0.220	-0.015
CHQ	0.289	-0.022	0.262	0.421	0.522	0.289	0.289	0.289	0.289
FUJ	0.464	0.077	0.464	-0.477	-0.455	0.465	0.466	0.466	0.466
GAN	-0.257	0.401	0.266	0.470	0.563	0.773	0.774	0.774	0.774
GUD	0.400	-0.498	0.399	-1.674	-2.176	-2.006	-2.858	-2.021	-2.028
GXI	0.223	-0.080	0.223	-0.448	-0.254	0.224	0.224	0.224	0.224
GZH	-0.209	0.548	0.925	-0.064	0.103	0.965	0.965	0.965	0.966
HAI	0.045	-0.015	0.045	0.003	0.040	0.045	0.045	0.045	0.045
HEB	-2.256	-0.414	-0.516	-0.650	-0.500	-2.215	-0.501	-1.380	-0.388
HEN	-0.552	-0.302	0.475	-0.496	-0.200	-0.829	-0.717	-0.477	0.477
HLJ	0.347	-0.101	0.131	0.911	1.009	0.347	0.347	0.347	0.347
HUB	1.301	0.771	1.315	-0.366	-0.158	1.315	1.315	1.315	1.315
HUN	0.635	0.144	0.635	0.381	0.632	0.634	0.635	0.634	0.635
JIL	0.010	0.112	-0.348	-0.058	0.047	0.571	0.572	0.571	0.572
JSU	0.357	-0.475	-0.269	-1.523	-1.876	-2.469	-2.933	-2.747	-2.732
JXI	0.308	0.012	0.308	-0.089	0.073	0.308	0.308	0.308	0.308
LIA	-0.926	-0.187	-0.933	-0.023	-0.019	-0.292	0.477	0.082	-0.255
NMG	-1.308	0.069	-1.509	0.753	0.746	0.659	0.727	0.727	0.267
NXA	0.079	-0.005	-0.020	0.035	0.060	0.079	0.079	0.079	0.079
QIH	-0.321	0.087	-0.581	0.034	0.051	0.302	0.302	0.302	0.302
SHA	0.277	-0.021	0.277	0.799	0.930	0.277	0.277	0.277	0.277
SHD	-1.584	-0.576	0.054	-1.032	-1.081	-3.509	-3.071	-3.485	-2.600
SHH	0.259	-0.263	-1.549	-0.904	-1.833	0.261	-0.132	0.261	-1.424
SHX	-0.984	0.031	-0.600	2.967	3.052	0.616	0.616	0.616	0.617
SIC	0.244	-0.256	0.244	-0.226	0.106	0.244	0.245	0.244	0.244
TAJ	0.319	-0.024	-0.941	0.146	-0.033	0.321	0.322	0.321	0.221
XIN	0.507	0.199	0.051	0.674	0.746	0.506	0.507	0.506	0.507
YUN	0.879	0.786	1.183	-0.177	0.014	1.184	1.183	1.183	1.183
ZHJ	0.801	0.105	-0.037	0.137	-0.247	0.284	-1.117	-1.080	-1.105
Eastern	-1.901	-2.335	-3.666	-5.510	-8.310	-8.894	-9.081	-9.318	-9.815
Central	0.188	0.699	0.836	3.992	5.469	4.052	4.236	4.474	4.970
Western	1.712	1.636	2.830	1.518	2.841	4.842	4.845	4.844	4.846

A8. WELFARE IMPACTS BY PROVINCE

Table A6. Welfare impacts in terms of percentage changes of equivalent variation of income by province.

Region	ERE	SOV	EGA	EQU	PRG	PPP	ESU	CPP	ABT
ANH	-0.165	-1.117	-0.166	-1.051	-0.483	-0.151	-0.151	-0.156	-0.160
BEJ	-1.622	-2.260	-2.995	-1.051	-2.453	-1.659	-1.642	-1.654	-2.188
CHQ	-1.517	-2.663	-1.611	-1.051	-0.666	-1.516	-1.529	-1.523	-1.517
FUJ	0.824	0.051	0.801	-1.051	-1.025	0.761	0.742	0.745	0.740
GAN	-5.883	-1.497	-2.388	-1.051	-0.425	0.974	0.993	0.987	0.996
GUD	0.156	-0.368	0.172	-1.051	-1.331	-1.234	-1.722	-1.235	-1.231
GXI	0.900	0.022	0.899	-1.051	-0.492	0.898	0.904	0.900	0.901
GZH	-1.726	1.647	3.309	-1.052	-0.315	3.492	3.492	3.492	3.492
HAI	-0.451	-1.270	-0.479	-1.051	-0.596	-0.528	-0.561	-0.550	-0.564
HEB	-3.721	-0.614	-0.768	-1.051	-0.788	-3.657	-0.754	-2.241	-0.563
HEN	-1.144	-0.794	0.266	-1.051	-0.640	-1.501	-1.341	-1.018	0.282
HLJ	-2.828	-4.189	-3.477	-1.051	-0.744	-2.791	-2.789	-2.789	-2.784
HUB	2.121	1.116	2.143	-1.051	-0.656	2.137	2.142	2.140	2.142
HUN	-0.580	-1.461	-0.575	-1.051	-0.596	-0.580	-0.566	-0.571	-0.569
JIL	-0.846	-0.574	-1.871	-1.051	-0.776	0.687	0.679	0.676	0.663
JSU	0.566	-0.148	0.025	-1.051	-1.356	-1.790	-2.195	-2.039	-2.037
JXI	0.239	-0.714	0.240	-1.051	-0.533	0.232	0.234	0.234	0.237
LIA	-2.620	-1.335	-2.633	-1.051	-1.043	-1.520	-0.183	-0.871	-1.458
NMG	-8.784	-3.649	-9.496	-1.050	-1.063	-1.448	-1.172	-1.181	-2.866
NXA	-0.203	-1.801	-2.111	-1.051	-0.605	-0.259	-0.294	-0.282	-0.295
QIH	-10.763	0.376	17.887	-1.053	-0.580	6.218	6.232	6.232	6.238
SHA	-2.898	-3.868	-2.908	-1.051	-0.621	-2.846	-2.843	-2.849	-2.863
SHD	-1.507	-0.626	-0.066	-1.051	-1.104	-3.243	-2.869	-3.231	-2.451
SHH	0.858	0.009	-1.943	-1.051	-2.485	0.766	0.136	0.745	-1.839
SHX	-16.907	-12.764	-15.327	-1.052	-0.712	-10.412	-10.392	-10.401	-10.397
SIC	-0.301	-1.095	-0.299	-1.051	-0.520	-0.294	-0.288	-0.290	-0.288
TAJ	-0.054	-1.780	-6.202	-1.050	-1.920	-0.136	-0.192	-0.173	-0.667
XIN	-1.954	-3.497	-4.251	-1.051	-0.681	-1.928	-1.931	-1.930	-1.926
YUN	2.382	2.076	3.370	-1.051	-0.426	3.358	3.370	3.366	3.376
ZHJ	-0.243	-1.013	-1.149	-1.051	-1.469	-0.870	-2.338	-2.294	-2.337
Eastern	-0.582	-0.634	-0.788	-1.051	-1.401	-1.479	-1.496	-1.530	-1.583
Central	-2.102	-1.953	-1.932	-1.051	-0.664	-1.056	-1.003	-0.947	-0.824
Western	-1.002	-1.024	-0.574	-1.051	-0.524	0.253	0.256	0.254	0.256

A9. COMPARISON OF ETS SCENARIOS TO REGIONAL EMISSIONS-INTENSITY TARGETS

For comparison to the regional emissions-intensity targets of the Twelfth Five-Year Plan, we simulate their welfare impacts by using the energy-economic model outlined in Section 3 (see also Zhang et al., 2013). The regional emissions-intensity targets of the Twelfth Five-Year Plan are differentiated by province (see **Table A3** in **Appendix A4**). **Figure A3** shows the welfare impacts of the regional emissions-intensity targets and those of the different ETS allocation scenarios.

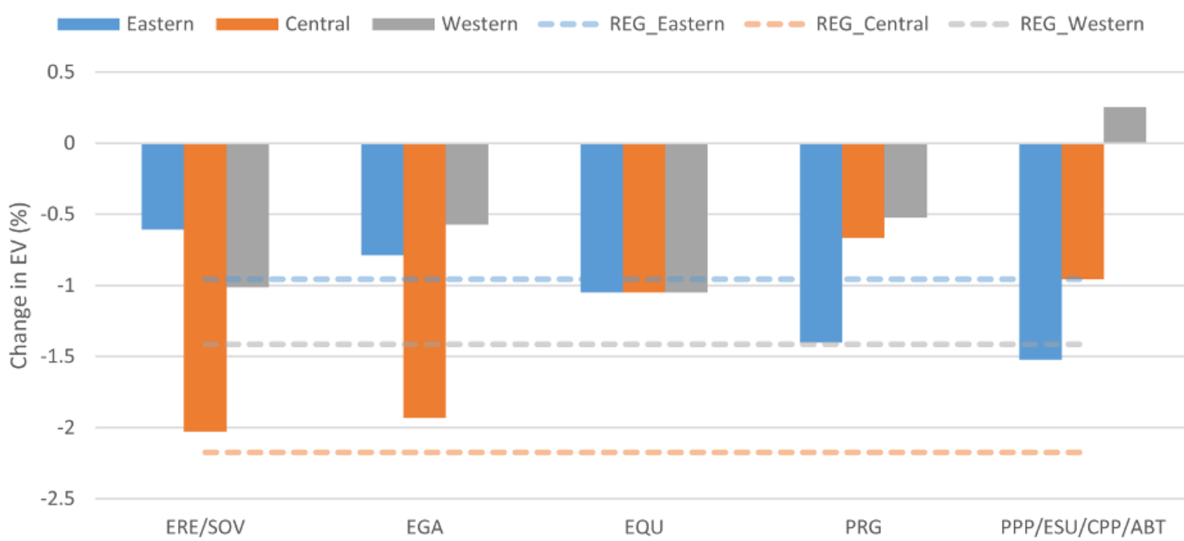

Figure A3. Welfare impacts in terms of equivalent variation of income (%) for China's eastern, central, and western regions in the different allocation scenarios. The dashed horizontal lines indicate the welfare changes associated with the regional emissions-intensity targets of the Twelfth Five-Year Plan (expressed as static emissions-reduction equivalents).

A10. INSTITUTIONAL AFFILIATIONS OF TARGETED FOCUS GROUP MEMBERS

Table A7. Institutional affiliations of target group members.

Affiliations of target group members
Beijing Institute of Technology
Beijing Normal University
Chinese Academy of Sciences
Chinese Academy of Social Sciences
China Agricultural University
China Guodian Energy Research Institute
China University of Petroleum
Chongqing Technology and Business University
Development Research Center of the State Council
Energy Research Institute of the NDRC
Fudan University
Guangzhou Institute of Energy Conversion
Hunan University
Renmin University of China
Shanghai Academy of Social Sciences
Shanghai Environment and Energy Exchange
State Information Center
Tianjin University of Science and Technology
Tsinghua University
Wuhan University

A11. CHARACTERISTICS OF SURVEY PARTICIPANTS

Table A8. Description of survey participants.

Participants' characteristics		Frequency	Percent
Affiliation	Academic	41	93.18
	Government	1	2.27
	Other	2	4.55
Age	Below 30	23	52.27
	30 or above	14	31.82
	No information	7	15.91
Gender	Female	17	38.64
	Male	26	59.09
	No Information	1	2.27
Origin	East	19	43.18
	Central	19	43.18
	West	5	11.36
	No Information	1	2.27
Residence	East	34	77.27
	Central	8	18.18
	West	1	2.27
	No Information	1	2.27

A12. RESPONDENTS' PREFERENCES BY REGION OF ORIGIN AND RESIDENCE

Table A9. Respondents' final preference for the different ETS allocation scenarios differentiated by region of origin.

Final preference	Region of origin				Total
	East	Center	West	No information	
SOV/ERE	1	1	2	0	4
EGA	2	1	0	0	3
EQU	2	3	0	0	5
PRG	6	6	0	1	13
PPP/CPP/ABT/ESU	8	8	3	0	19
Total	19	19	5	1	44

Table A10. Respondents' final preference for the different ETS allocation scenarios differentiated by region of residence.

Final preference	Region of residence				Total
	East	Center	West	No information	
SOV/ERE	3	1	0	0	4
EGA	2	1	0	0	3
EQU	4	1	0	0	5
PRG	8	4	0	1	13
PPP/CPP/ABT/ESU	17	1	1	0	19
Total	34	8	1	1	44

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