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Consumption-Based Adjustment of Emissions-Intensity Targets: An Economic Analysis for China's Provinces

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Abstract China's Twelfth Five-Year Plan (2011–2015) aims to achieve a national carbon intensity reduction of 17 % through differentiated targets at the provincial level. Allocating the national target among China's provinces is complicated by the fact that more than half of China's national carbon emissions are embodied in interprovincial trade, with the relatively developed eastern provinces relying on the center and west for energy-intensive imports. This study develops a consistent methodology to adjust regional emissions-intensity targets for trade-related emissions transfers and assesses its economic effects on China's provinces using a regional computable-general-equilibrium (CGE) model of the Chinese economy. This study finds that in 2007 China's eastern provinces outsource 14 % of their territorial emissions to the central and western provinces. Adjusting the provincial targets for those emissions transfers increases the reduction burden for the eastern provinces by 60 %, while alleviating the burden for the central and western provinces by 50 % each. The CGE analysis indicates that this adjustment could double China's national welfare loss compared to the homogenous and politics-based distribution of reduction targets. A shared-responsibility approach that balances production-based and consumption-based emissions responsibilities is found to alleviate those unbalancing effects and lead to a more equal distribution of economic burden among China's provinces.

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1 Introduction

Reducing the anthropogenic emissions of greenhouse gases (GHGs) linked to climate change is a major challenge for international environmental policy. China surpassed the US in 2007 to become the world's largest emitter of carbon dioxide (CO_2) (International Energy Agency (IEA) 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 40–45 % from 2005 levels by 2020.[1] China's Twelfth Five-Year Plan (FYP) for economic and social development (2011–2015) has integrated part of this commitment into binding national policy, targeting a 17 % decrease in national carbon intensity over the same period (State Council of China 2012).[2]

How to assign responsibility for the cost and actions required to reduce emissions without undermining economic growth and development goals is a major current policy question in China. Within China pronounced differences exist between the developed eastern-coastal provinces and the less developed central and western provinces (Keidel 2009; Feng et al. 2009). For example, the per-capita GDP between the coastal municipality of Shanghai and the southwest province of Guizhou differs by a factor of ten (National Statistics Bureau of China 2008). On aggregate, the per-capita GDP in the inland regions is less than half of that in the coastal regions (Fan et al. 2011). Those disparities lead to large differences in regional CO_2 emissions and emissions intensities, with the eastern-coastal provinces having relatively higher emissions but lower emissions intensities than the central and western provinces (Meng et al. 2011; Feng et al. 2012; Liu et al. 2012).

Interprovincial trade contributes to China's uneven regional distribution of production and consumption activities and their associated emissions. CO_2 emissions embodied in interprovincial trade have accounted for as much as 64 % of China's total CO_2 emissions in 2002 (Guo et al. 2012). On net, emissions transfers occur from the eastern-coastal provinces to the central and western provinces (Liang et al. 2007; Guo et al. 2012; Meng et al. 2011). Thus, the eastern-coastal provinces outsource part of their emissions by importing energy-intensive and energy-related goods, without being held accountable for the emissions embodied in those imports (Guo et al. 2012). In turn, the central and western provinces experience a greater burden as they increase their emissions to produce for interregional export.

Previous experience with regional energy-intensity targets has shown that allocating a national target homogenously to each province can further perpetuate regional disparities and incur large costs in some provinces.[3] In part to avoid these concerns the Twelfth FYP

[1] This commitment was made at the 15th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Copenhagen in December 2009.

[2] Prior to the Twelfth Five-Year Plan, the Eleventh Five-Year Plan and its predecessors focused on energy intensity (and did not set a target for carbon intensity). The Eleventh Five-Year Plan included a target to reduce energy intensity by 20 % nationwide. The target was not formally allocated to provinces but comprised of pledges made by each province (World Bank 2009).

[3] A near-homogenous setting of energy (instead of carbon) intensity targets in the Eleventh FYP (by collecting and renegotiating provincial pledges) had pushed some provinces to adopt extreme short-term measures, such as rolling black-outs, to fulfill their target.

differentiated the carbon-intensity targets by province based on political negotiations, ranging from 10 % carbon-intensity reductions for some western provinces (Qinghai and Tibet) to 19.5 % in the eastern-coastal province of Guangdong. However, researchers have argued that a more transparent and science-based methodology should guide the setting of future energy and carbon targets on the provincial level (Ohshita et al. 2011).

This study contributes to this discussion. First, it develops a methodology for adjusting provincial emissions-intensity targets for the interregional emissions transfers that occur between China's provinces. In correcting for emissions transfers, this policy implementation highlights the magnitude of emissions-intensity reduction that would be necessary if provinces were held responsible for the emissions driven by their consumption demand. Second, the study simulates the effects of such a target allocation by employing an interregional computable-general-equilibrium (CGE) model of the Chinese economy which provides a comprehensive representation of regional market interactions through price and income-responsive supply and demand responses (see Zhang et al. 2012).

This study finds that adjusting the provincial targets for interregional emissions transfers increases the reduction burden for the eastern provinces by about 60 %, while alleviating the burden for the central and western provinces by about 50 % each. The CGE analysis indicates that this adjustment could double China's national welfare loss compared to a homogenous distribution of reduction targets. The welfare losses for the eastern provinces increase by a factor of four, while providing little relief for the central and western provinces. A shared-responsibility approach that balances production-based and consumption-based emissions responsibilities is found to alleviate those unbalancing effects and lead to a more equal distribution of economic burden among China's provinces.

The study is structured as follows. Section 2 contains a detailed review of previous academic contributions assessing methods for target allocation, emissions transfers, and consumption-based emissions accounts. Section 3 presents our methodology for deriving trade-adjusted emissions-intensity targets. Section 4 outlines the CGE model employed in this study, as well as its database and regional aggregation. Section 5 details the consumption-based adjustment of China's emissions-intensity targets. It describes the policy scenarios considered, calculates interregional emissions transfers within China, and applies the target-adjustment methodology for this context. Section 6 contains the CGE model results, comparing the economic effects of a consumption-based adjustment of emissions-intensity targets (accounting for trade-related emissions transfers) with those following a shared-responsibility approach, a production-based approach with uniform targets for each province, and the current politically negotiated targets.

2 Literature Review

This study is related to two strands of literature. Studies in the first strand develop indices for informing the regional allocation of emissions targets, while studies in the second strand construct consumption-based emissions inventories for highlighting the flows and distributional implications of the emissions embodied in trade. The following reviews the studies most relevant to this one, highlights the gaps in the literature, and indicates this study's contribution.

2.1 Previous Approaches for Target Allocation

Previous analyses have proposed several aggregate indices for informing the regional allocation of carbon-intensity reduction targets in China. For example, Wei et al. (2011) have constructed an abatement capacity index based on weighted equity and efficiency indices. Based on time series data from 1995 to 2007, the equity index includes per-capita CO_2 emissions and per-capita GDP, while the efficiency index includes regional emissions intensity and marginal-abatement costs. Yi et al. (2011) have constructed an aggregate index for informing the carbon intensity allocation in 2020. Their index is based on per-capita GDP (to indicate the capacity for emissions reduction), accumulated fossil-fuel related CO_2 emissions (to indicate the responsibility for emissions reduction), and energy consumption per unit of industrial value added (to indicate the potential for emissions reduction). Finally, Ohshita et al. (2011) combine top-down national target projections and bottom-up provincial and sectoral projections to suggest an allocation among Chinese provinces for the national target of 20 % energy intensity improvements during the Twelfth FYP.

2.2 Interregional Emissions Transfers

While the target allocation methods described above aim to address equity issues by including per-capita indices of emissions and GDP, they do not account for the potential impact that interregional trade can have on the stringency and distributional aspects of regional emissions targets. Studies on the international level have found that trade can make compliance with emissions-reduction targets easier for regions that import emissions-intensive products without producing them and harder for those regions that are exporting such products (Wyckoff and Roop 1994; Munksgaard and Pedersen 2001). Industrialized countries, in particular, have been found to be net importers of emissions embodied in trade, while developing countries are found to be net exporters (Peters and Hertwich 2008). With respect to China, Davis and Caldeira (2010) have estimated that 22.5 % of the emissions produced in China in 2004 were exported, on net, to consumers elsewhere, primarily to those in developed countries (see also Shui and Harriss 2006; Wang and Watson 2008; Lin and Sun 2010).

The issue of emissions transfers is mirrored and amplified on the regional level due to China's uneven regional distribution of production and consumption activities. CO_2 emissions embodied in interprovincial trade in 2002 have exceeded those embodied in China's international exports by a factor of three (Guo et al. 2012). On net, emissions transfers occur from the eastern-coastal provinces to the central and western provinces (Liang et al. 2007; Guo et al. 2012; Meng et al. 2011), primarily through the trade in energy-intensive products, such as steel, but also through energy transfers as most coal resources are located in the western and central provinces. Thus, the eastern-coastal provinces outsource part of their emissions by importing energy-intensive and energy-related goods, without being held accountable for the emissions embodied in those imports. In turn, the central and western provinces experience a greater burden as they increase their emissions to produce for interregional export. The interregional emissions transfers therefore distort the regional allocation of China's emissions-intensity target and make it less equitable by failing to account for emissions on a consumption basis.

2.3 Consumption-Based Emissions Allocation

Consumption-based emissions inventories have been proposed to account for the trade-induced separation of production from consumption and the associated distributional consequences of emissions transfers (Peters and Hertwich 2008). A consumption-based inventory includes the emissions embodied in imports and subtracts those embodied in exports (Munksgaard and Pedersen 2001; Munksgaard et al. 2005). Compared to the polluter-pays principle of the production-based approach, it stresses the emissions responsibility of the beneficiary, i.e., the consumer of the good, for the emissions generated in the production process. For the Chinese context, Guo et al. (2012) have constructed a consumption-based emissions inventory for China's provinces and calculated consumption-based regional emissions intensities.[4]

However, while consumption-based emissions inventories have been used regularly as a lens to study the distributional consequences of emissions transfers (see e.g., Wiedmann et al. 2007), there is little research on how to integrate a consumption-based approach in policy-making and what the potential impacts would be. In the literature on international climate policy design, the main problem of consumption-based approaches is that they extend the reach of climate policies across regional borders, which makes them incompatible with regional sovereignty. This study addresses this problem by deriving trade-adjusted emissions-intensity targets that can be implemented without violating regional sovereignty. Instead they only require agreement on the target allocation. In correcting for emissions transfers, trade-adjusted emissions-intensity targets highlight the magnitude of emissions-intensity reduction that would be necessary if provinces were held responsible for the emissions driven by their consumption demand.

A potential problem of adjusting emissions-reduction targets is that the adjusted targets may overburden highly emissions-exporting regions as their targets would become significantly more stringent. We therefore also consider a shared-responsibility approach to emissions accounting in this study and compare its economic and distributional impacts with those following from purely consumption-based and production-based approaches. It has frequently been argued that both the consumption-based and the production-based conceptions of responsibility represent extreme views and that a shared-responsibility approach may be an appropriate solution to address the distributional impacts of emissions generation and economic activity (Bastianoni et al. 2004; Gallego and Lenzen 2005; Lenzen et al. 2007).[5]

3 Trade-Adjusting Emissions-Intensity Targets

In this section, we derive trade-adjusted emissions-intensity targets which are based on a consumption-based and shared-responsibility approach, but which can be implemented in a production-based system to account for interregional emissions transfers. Due to our application to China, we concentrate on emissions-intensity targets. However, the derivations can be easily adopted to also adjust absolute emissions targets for consumption responsibilities.

3.1 Production-Based Emissions Intensities

In a production-based system, a region's emissions intensity (EI_r^{PRD}) is defined as the ratio of territorial emissions (e_r^{PRD}) to a unit of economic activity, usually taken to be GDP:

$$EI_r^{PRD} = \frac{e_r^{PRD}}{GDP_r} \tag{1}$$

[4] Their results indicate higher emissions intensities for the emissions-exporting eastern-coastal provinces and lower emissions intensities for the emissions-importing central and western provinces. The analysis is
Footnote 4 continued
based on data from the year 2002. As a part of this study, we recalculate the emissions embodied in China's interregional trade using an updated dataset for the year 2007.

[5] For example, the consumer of a good gains from its consumption, while the producer gains from its production and sale. Similarly on the regional level, standard trade theory knows many cases in which each trading partner gains. Producing for export raises one region's GDP, while importing products increases the varieties on offer and may reduce prices for consumers who then increase consumption.

Mandates for reductions in emissions intensity are commonly expressed as percentage reductions of baseline emissions intensities ($r_{EI,r}^{PRD}$). The corresponding absolute emissions-intensity targets are obtained by subtracting the share of percentage emissions-intensity reductions from the baseline emissions intensities:

$$t_{EI,r}^{PRD} = \left(1 - r_{EI,r}^{PRD}\right) EI_r^{PRD} \tag{2}$$

The total emissions-intensity target (T_{EI}^{PRD}) is given by the GDP-weighted average of the regional emissions-intensity targets:

$$T_{EI}^{PRD} = \frac{\sum_r t_{EI,r}^{PRD} GDP_r}{\sum_r GDP_r} = \frac{\sum_r \left(1 - r_{EI,r}^{PRD}\right) e_r^{PRD}}{GDP} \tag{3}$$

where *GDP* denotes total GDP summed over all regions.

3.2 Consumption-Based Emissions Intensities

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}):

$$e_r^{CON} = e_r^{PRD} + e_r^{IM} - e_r^{EX} = e_r^{PRD} + B_r \tag{4}$$

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

Consumption-based emissions intensities (EI_r^{CON}) can be calculated by adding the ratio of emissions transfers to GDP to the production-based emissions intensities:

$$EI_r^{CON} = \frac{e_r^{PRD} + B_r}{GDP_r} \tag{5}$$

Regions which are net importers of embodied emissions (with positive B_r) have higher emissions intensities under the consumption-based approach, while the emissions intensities of net exporting regions (with negative B_r) are lower compared to those in the production-based approach.

3.3 Trade-Adjusted Emissions-Intensity Targets

The study's objective is to account for consumption responsibilities in a production-based system. We therefore calculate adjusted emissions-intensity reduction targets, while continuing to use the production-based emissions intensities as baselines. There are several ways of adjusting the production-based emissions-intensity targets to account for consumption responsibilities. However, not all possibilities conserve the total emissions-intensity target defined in the production-based approach.[6] A consistent method is to subtract the ratio of emissions transfers to GDP from the production-based emissions-intensity targets:

[6] For example, one could argue that the emissions-intensity targets should not be adjusted by all of a region's emissions transfers, but only by some proportion (e.g., by the regional percentage emissions-reduction target $r_{EI,r}^{PRD}$, such that $t_{EI,r}^{CON2} = (1 - r_{EI,r}^{PRD}) EI_r^{PRD} - r_{EI,r}^{RDP} \frac{B_r}{GDP_r}$). Similarly, one could argue that emissions transfers should be normalized by the GDP of the emissions-exporting regions ($t_{EI,r}^{CON3} = \left(1 - r_{EI,r}^{PRD}\right) EI_r^{PRD} - \sum_s \frac{B_{s,r}}{GDP_s}$). While those approaches might have some intuitive appeal, they do not preserve the total emissions-intensity target as, unlike in Eq. (8), the adjustments to the production-based emissions-intensity targets do not sum to zero.

$$t_{EI,r}^{CON} = \left(1 - r_{EI,r}^{PRD}\right) EI_r^{PRD} - \frac{B_r}{GDP_r} \tag{6}$$

The intuition is that regions which are net importers of embodied emissions (i.e., with positive B_r) have to bear stricter (i.e., lower) emissions-intensity targets, while the emissions-intensity targets of net exporters of embodied emissions are relaxed.

The associated percentage emissions-intensity reductions that would need to be applied to the production-based emissions-intensity baseline can be obtained by bringing the consumption-based emissions-intensity target into the form: $t_{EI,r}^{CON} = (1 - r_{EI,r}^{CON}) EI_r^{PRD}$. This yields the trade-adjusted percentage emissions-intensity reductions as:

$$r_{EI,r}^{CON} = r_{EI,r}^{PRD} + \frac{B_r}{GDP_r\ EI_r^{PRD}} = r_{EI,r}^{PRD} + \frac{B_r}{e_r^{PRD}} \tag{7}$$

Regions with net imports of embodied emissions would be subjected to greater percentage emissions-intensity reductions, while the reductions of regions which are net exporters of embodied emissions would be lowered.

The method for adjusting regional EI-targets for emissions transfers as described above preserves the total emissions-intensity target given by the GDP-weighted average of the regional emissions-intensity targets:

$$T_{EI}^{CON} = \frac{\sum_r t_{EI,r}^{CON} GDP_r}{\sum_r GDP_r} = \frac{\sum_r \left(1 - r_{EI,r}^{PRD}\right) e_r^{PRD} - \sum_r B_r}{GDP} = T_{EI}^{PRD} \tag{8}$$

where it was used that the sum of all emissions transfers is zero, since one country's imports is another country's exports: $\sum_r B_r = \sum_r e_r^{IM} - \sum_r e_r^{EX} = 0$.[7]

In our application, applying a consumption-based approach to regulate emissions-intensity reductions of Chinese provinces results in emissions-intensity targets that would allow some provinces to increase their emissions. Since this would set incentives inconsistent with the overall reduction goal, we set the targets of those provinces to their baseline levels. We redistribute the spare allowances created to keep the total emissions-intensity target fixed.

The total absolute emissions allowances to be redistributed are given by:

$$T^{red} = \sum_r (t_{EI,r}^{old} - t_{EI,r}^{new}) GDP_r = \sum_r \left(r_{EI,r}^{new} - r_{EI,r}^{old}\right) e_r = -\sum_r r_{EI,r}^{old} e_r \tag{9}$$

where the adjusted (new) emissions-intensity targets are set to baseline levels, i.e., $r_{EI,r}^{new} = 0$.[8]

Redistributing the emissions allowances among the remaining regions (n_{adj}) in proportion to their GDP yields adjusted emissions-intensity targets for those regions, and bringing the adjusted emission-intensity targets into the form $t_{EI,r}^{adj} = (1 - r_{EI,r}^{adj})\ EI_r^{PRD}$ yields the adjusted emissions reductions:

$$t_{EI,r}^{adj} = \left(1 - r_{EI,r}^{CON}\right) EI_r^{PRD} + \frac{T^{red}}{n_{adj} GDP_r} \tag{10}$$

$$r_{EI,r}^{adj} = r_{EI,r}^{CON} - \frac{T^{red}}{n_{adj} e_r} \tag{11}$$

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7 While the total emissions-intensity target is conserved in the static framework described above, it should be noted that the resulting emissions intensities may differ from the target due to changes in GDP. However, sensitivity analyses conducted for this study indicate that the deviations from the total emissions-intensity target amount to <0.4 % percentage points (2.5 %) for the model scenarios considered.

8 The total emissions to be redistributed, T^{red}, are positive because $r_{EI,r}^{old}$ are negative reductions (i.e., increases) in the provinces whose emissions-reduction targets are to be adjusted.

Thus, redistributing the spare allowances of those regions which would otherwise increase their emissions intensities relaxes the reduction targets of the remaining regions in (inverse) proportion to the remaining regions' emissions.

3.4 Shared Responsibility for Emission-Intensity Reductions

The production-based accounting system stresses the emissions responsibility of the producer, while the consumption-based system stresses that of the consumer. In the following, we derive a shared-responsibility approach to target allocation that balances the production-based approach and the consumption-based approach.

Allocating shared responsibilities along a good's value chain is sensitive to sectoral aggregation (Lenzen et al. 2007). However, two accounting principles with the same total emissions-intensity target can be readily combined. We therefore define the shared emissions-intensity target as a proportional split between the production-based intensity target and the consumption-based one:

$$t_{EI,r}^{SHR} = \frac{1}{2} t_{EI,r}^{PRD} + \frac{1}{2} t_{EI,r}^{CON} \tag{12}$$

The associated percentage reductions can be obtained by calculating $t_{EI,r}^{SHR}$ with the equation above, imposing the standard form $t_{EI,r}^{SHR} = (1 - r_{EI,r}^{SHR})\, EI_r^{PRD}$, and solving for $r_{EI,r}^{SHR}$:

$$r_{EI,r}^{SHR} = \frac{1}{2} \left(r_{EI,r}^{PRD} + r_{EI,r}^{CON} \right) \tag{13}$$

Thus, the percentage reduction targets under shared responsibility are given by a simple average between production-based and consumption-based reduction targets.

While there are several ways of accounting for shared responsibility between consumers and producers for allocating emissions-reduction burden,[9] the benefit of the method outlined above is that it illustrates how two potentially independent indicators for emissions-intensity reductions can be combined. In particular Eq. (12) can be generalized to combine different indicators which inform emissions-intensity targets into an aggregate reduction index. Indicators other than the emissions-based ones used in this study may include economic ones, such as per-capita GDP, or temporal ones, such as historical emissions (Yi et al. 2011; Wei et al. 2011). The general form of a composite indicator is then:

$$t_{EI,r}^{AGG} = \frac{1}{n_{agg}} \sum_i t_{EI,r}^i; \quad r_{EI,r}^{AGG} = \frac{1}{n_{agg}} \sum_i r_{EI,r}^i \tag{14}$$

where n_{agg} denotes the number of indicators to be aggregated.

4 Model Description

This study utilizes an energy-economic model with regional detail for the Chinese economy. A detailed model description is provided by Zhang et al. (2012). In short, the model is a computable general equilibrium model based on optimizing behavior of economic agents.

[9] For example, one could define shared-responsibility emission-intensity target by trade-adjusting the production-based target by half of a region's emissions transfers, i.e., $t_{EI,r}^{SHR} = (1 - r_{EI,r}^{PRD}) EI_r^{PRD} - \frac{1}{2} \frac{B_r}{GDP_r}$. This method also leads to a consistent allocation of emissions-reduction burden in that is preserved the total emissions-intensity target.

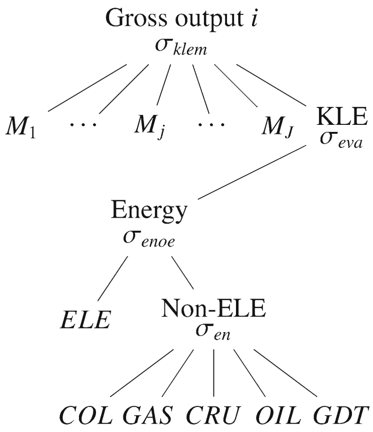

Fig. 1 Nesting structure of CES production functions for non-energy goods

Consumers maximize welfare subject to budget constraints and producers combine intermediate inputs and primary factors at least cost to produce output. Energy resources are included as primary factors whose use is associated with the emission of carbon dioxide (CO_2). 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.[10]

4.1 Model Structure

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 Fig. 1). 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 and a composite of primary factors and energy, described by a Cobb–Douglas function of energy inputs, 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,

10 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).

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 non-malleable 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 interregional 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.

4.2 Database and Aggregation

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 dataset 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). The GTAP 8 data set provides consistent global accounts of production, consumption and bilateral trade as well as consistent accounts of physical energy flows, energy prices and emissions for the year 2007, and identifies 129 countries and regions and 57 commodities (Narayanan et al. 2012). Since in this study, we are primarily interested in the economic and distributional effects among Chinese provinces, we aggregate the international data into three international regions (USA, Europe, and the rest of the world) to capture the international market impacts of distributional changes within China. With respect to commodities, we include six energy sectors and 10 non-energy composites.[11]

The data for China is based on China's national input-output table and the full set of China's provincial input-output tables for 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 and emissions data is based on the 2007 China Energy Statistical Yearbook (National Statistics Bureau of China 2008). Zhang et al. (2012) describe in detail the method used for balancing the Chinese data set and combining it with the international one. Elasticities of substitution are adopted from the GTAP 8 database, as well as from the MIT Emissions Prediction and Policy Analysis model (Paltsev et al. 2005), in particular for the price elasticities of supply of nuclear, hydro, and wind. Table 5 in the "Appendix 1" provides an overview of the elasticities used in this study.

Figure 2 shows the provinces included in the analysis. We explicitly simulate the policy scenarios' effects for all 30 Chinese provinces for which data is available. To ease the

[11] The energy goods include coal (COL), crude oil (CRU), refined-oil 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).

Fig. 2 Overview of Chinese provinces included in the analysis. The eastern provinces include Beijing (BEJ), Fujian (FUJ), Guandong (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)

Table 1 Regional emissions, GDP, and emissions intensities

Region	Emissions ($MTCO_2$)	GDP (billion USD)	Emissions intensity ($MtCO_2$/billion USD)
Eastern	2,639	2,278	1.16
Central	1,801	943	1.91
Western	1,224	542	2.26
China	5,664	3,763	1.51

presentation of results, we group those provinces according to the three economic zones defined in China's Seventh FYP (State Council of China 1986; Feng et al. 2012), i.e., into eastern, central, and western zones. The eastern provinces are the economically most developed regions with high levels of industrialization and rapid growth in international trade in recent decades. Based on the Chinese database, Table 1 indicates that the eastern provinces' total GDP is more than double that of the central provinces and more than four times that of western provinces. They are also the greatest emitters of CO_2 in China. However, due to their more advanced economic development they have the lowest emissions intensity. The central provinces have well-established infrastructures and abundant natural resources, such as coal, oil, and metal ores. They are relatively less developed compared to the eastern provinces, although provinces, such as Inner Mongolia (Neimenggu) are industrializing rapidly. The central provinces' total emissions are more than 30 % lower than those of the eastern provinces, but their emissions intensity is 65 % higher (Table 1). The western provinces are the least developed ones, but provinces such as Xinjiang have abundant oil and natural-gas reserves. The western provinces' total emissions are more than 50 % lower than those in the eastern provinces, but their emissions intensity is almost double (Table 1).

5 Consumption-Based Emissions-Intensity Targets for China's Provinces

This section applies the general methodology for adjusting emissions-intensity targets for emissions transfers to the Chinese context. It lays out the model scenarios considered, computes interregional emissions transfers, and derives adjusted emissions-intensity targets for China's provinces.

5.1 Model Scenarios

This study considers four model scenarios to evaluate the economic and distributional effects of implementing consumption-based emissions-intensity targets for China's provinces. The scenarios considered differ with respect to their method of allocating the emissions-intensity targets. The production-based (**PRD**) scenario follows a territorial and production-based accounting principle and allocates the same percentage emissions-intensity target to each province; the politics-based (**POL**) scenario follows the political decision-making process and adopts the emissions-intensity allocation that was politically negotiated for the Twelfth FYP; the consumption-based (**CON**) scenario follows a consumption-based accounting principle and adjusts emissions-intensity targets for interregional emissions transfers; lastly, the shared-responsibility (**SHR**) scenario takes a median approach in which emissions responsibilities and intensity targets are equally divided between the production-based principle and the consumption-based one. Each scenario targets an emissions-intensity reduction of 17.4 % nationally, which is in line with the target adopted by the Chinese government in its Twelfth FYP.[12]

5.2 Interregional Emissions Transfers

For obtaining the interregional emissions transfers we apply a recursive diagonalization algorithm as described in Böhringer et al. (2011).[13] Figure 3 provides an overview of China's interregional emissions transfers as calculated in this study. On net, the eastern provinces import about 350MtCO_2 of embodied emissions, i.e., 14 % of their territorial emissions. Sixty percent of those emissions (212MtCO_2) are embodied in imports from the central provinces and 40 % (136MtCO_2) in imports from the western provinces. The percentage

[12] Although we adopt the emissions-intensity target of the 12th FYP, we do not aim 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-intensity targets. To better isolate the effects relevant for this analysis, we use a static (instead of a dynamic) CGE framework based on data representing economic conditions for the year 2007.

[13] Böhringer et al. (2011) build a multiregional input-output model based on the GTAP data base and calculate the emissions embodied in international trade. We apply the same method to calculate the emissions embodied in interregional trade in China. We refer to Böhringer et al. (2011) for a detailed description of the general methodology.

Fig. 3 Emissions transfers between China's provinces. Positive numbers indicate a greater share of emissions embodied in imports than those embodied in exports (see Eq. 4)

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.

5.3 Consumption-Based Emissions-Intensity Targets

Adjusting the regional emissions-intensity targets on a consumption basis leads to a greater reduction burden for the eastern provinces and less burden for the central and western provinces. Table 2 lists the trade-adjusted emissions-intensity reduction targets which were obtained by applying the methodology outlined in Sect. 2, in particular Eqs. (7), (11), and (13). The reduction burden for the eastern provinces in the consumption-based (CAP) scenario increases by 10.4 percentage points (60 %) compared to the production-based (PAP) scenario with homogenous reduction targets. At the same time, the reduction burden for the central and western provinces is reduced by 10 and 8 percentage points (55 and 49 %) respectively. In comparison, the politics-based (POL) scenario is associated with a much milder redistribution of reduction burden. In that scenario, the eastern provinces' reduction targets are increased by 1.2 percentage points (7 %) compared to the PAP scenario, while the central and western provinces' reduction targets are decreased by 0.6 and 1.7 percentage points (4 and 10 %) respectively. Lastly, the shared-responsibility (SHR) scenario yields emission-intensity reduction targets that are given by the average between the production-based and the consumption-based targets. Thus, the eastern provinces' reduction burden increases by 5 percentage points (30 %) compared to the production-based scenario, while the burden of

Table 2 Regional emissions-intensity reduction targets in the production-based (PRD), politics-based (POL), consumption-based (CON), and shared-responsibility-based allocation scenarios

Region	PRD	POL	CON	SHR
Eastern	17.4	18.6	27.8	22.6
Central	17.4	16.8	7.9	12.6
Western	17.4	15.7	9.0	13.2
China	17.4	17.4	17.4	17.4

the central and western provinces decreases by 5 and 4 percentage points (27 and 24 %) respectively.

Paralleling emissions transfers, the trade-adjusted emissions-intensity targets show a larger spread than the averages suggest (see Table 6 in the "Appendix 2"). Especially the heavily importing eastern provinces of Zhejiang, Hainan, and Beijing are burdened greatly when following a consumption-based approach for target allocation. Their targets for emissions-intensity reductions increase from 17.4 % to over 85 %. On the other hand, the reduction targets for several emissions-exporting central and western provinces, such as Inner Mongolia and Shanxi (central), and Gansu, Guizhou, Qinghai, and Yunnan (western) become zero in the consumption-based approach.[14]

Figure 3 indicates that the aggregate regions of eastern, central, and western China do not map exactly to net emissions-exporting and emissions-importing provinces. Among the net emissions-importing provinces are nine eastern provinces, four central, and three western ones; among the net emissions-exporting provinces are seven western provinces, five central, and two eastern ones. The heterogeneous composition of those two groups decreases the maximum and minimum values in the regional aggregates used for reporting, which should be kept in mind when interpreting the results. The maximum and minimum economic impacts are mentioned in the results section wherever feasible to underline this distinction and the appendix provides a detailed overview of the economic impacts for each province.

6 Economic Effects of Consumption-Based Target Adjustments

This section applies the CGE model described in Sect. 4 to analyze the economic effects of adopting the different target-allocation methods described above. Implementing consumption-based and regionally differentiated emissions-intensity targets in China can be expected to lead to significant differences in economic and distributional impacts between China's provinces, especially when considering the large spread of reduction targets listed in Table 2. To capture those impacts sufficiently, we separately discuss the regional, provincial, and sectoral impacts.

6.1 Impacts on the Regional Level

This study assesses macroeconomic welfare effects in terms of Hicksian equivalent variation of income. The scenarios' effects on regional welfare are listed in Table 3 (top panel). The

[14] The emissions-intensity reduction targets of those provinces would actually become negative, i.e., allow for increases in emissions intensity. However, because we want to preserve incentives for not increasing emissions intensities on the provincial level, we constrain the maximum alleviation for emissions exporting provinces to be the homogenous reduction target of the production-based approach, i.e., 17.4 %. The provinces that would exceed this alleviation are allocated their baseline emissions intensities, i.e., a zero percent reduction target.

Table 3 Regional changes in welfare as measured by equivalent variation of income (top) and regional changes in GDP (bottom)

	PRD	POL	CON	SHR
EV (%)				
Eastern	−0.87	−0.96	−3.64	−1.20
Central	−2.26	−2.23	−1.90	−2.00
Western	−1.50	−1.44	−1.79	−1.43
China	−1.36	−1.39	−2.84	−1.46
GDP (%)				
Eastern	−0.32	−0.35	−1.27	−0.43
Central	−1.05	−1.04	−0.92	−0.94
Western	−0.69	−0.69	−0.85	−0.67
China	−0.56	−0.57	−1.12	−0.59

production-based scenario which implements homogenous emissions-intensity reductions of 17.4 % for each province leads to the greatest welfare losses in the central provinces (−2.26 %) relative to the no-policy case. The decreases in welfare are about a third less in the central provinces (−1.5 %) and another third less in the eastern provinces (−0.87 %) who are the least burdened. The politics-based scenario changes those trends only marginally. The eastern provinces' welfare decreases by 0.1 percentage points more than in the production-based scenario, with little alleviation of the negative welfare impacts for the central and western provinces.

The consumption-based scenario increases the reduction burden for the eastern provinces by 60 % and decreases the burden for central and western provinces by about 50 % each when compared to the production-based scenario. As a result, the eastern provinces become the highest burdened ones among China's regions, experiencing a more than four times larger negative welfare impact than in the production-based scenario. The decreases in welfare in the east are about two times larger than those of the central and western provinces. While the decrease in welfare that the central provinces experience is 16 % less than in the production-based scenario, the welfare loss in the western provinces is 20 % larger than in the production-based scenario despite the substantial alleviation of reduction burden for those provinces in the consumption-based scenario. The national welfare loss more than doubles in the consumption-based scenario compared to the production-based and politics-based scenarios.

The shared-responsibility scenario results in a more even distribution of the welfare impacts across provinces relative to the consumption-based scenario. The national welfare loss in the shared-responsibility scenario is about 7 and 4 % larger than in the production-based scenario and the politics-based scenario respectively (compared to 109 % in the consumption-based scenario). Although the eastern provinces are again the least burdened in the shared-responsibility scenario, the welfare losses for the central and western provinces are both reduced compared to the production-based and politics-based scenarios, by 12 and 4 % respectively.

Table 3 (lower panel) lists the changes in GDP for the policy scenarios considered. In principle, changes in GDP can differ from changes in equivalent variation as GDP focuses solely on the production side of the economy. Although the changes in GDP are less accentuated than the changes in EV, they follow the same direction in similar proportions.

6.2 Impacts on the Provincial Level

Individual provinces can bear much greater welfare impacts than the impacts for the aggregate regions suggest. Figure 4 highlights the five provinces which are burdened the most and the five which are burdened the least under the consumption-based scenario. A complete listing of welfare and GDP impacts is provided in Tables 7 and 8 in the “Appendix 3”. Three of the most heavily burdened provinces are in the east (Hainan, Zhejiang, Beijing), while one is in the center (Shanxi) and one in the west (Chongqing). With the exception of Shanxi, all of those provinces are net importers of embodied emissions and are therefore subjected to greater reduction targets in the consumption-based scenario. Shanxi is China’s greatest coal producer, possessing about one third of China’s coal reserves. It is therefore impacted significantly by all policies aimed at reducing China’s emissions intensity. The welfare losses of the five highest burdened provinces cover a large range, spanning percentage welfare changes of −6 to −33 % compared to the no-policy case. Those losses correspond to 2–22 times the magnitude of losses found in the production-based scenario.

Among the five least burdened provinces in the consumption-based scenario are two western provinces (Gansu, Guizhou), two central provinces (Hubei, Henan), and one eastern province (Hebei). All of those provinces are net exporters of embodied emissions and therefore are subjected to less stringent reduction targets in the consumption-based scenario. Three out of the five (Gansu, Guizhou, and Hebei) have a zero reduction target, i.e., they are allowed to keep their baseline emissions intensities due to their high exports of embodied emissions. The welfare gains range from 1 to 2 % compared to the no-policy case, which corresponds to factor increases of 0.5–5 compared to the production-based scenario’s welfare levels. Hubei and Guizhou are important energy producers, in particular for electricity generation. Those provinces experience welfare gains in all policy scenarios as the price for electricity increases following the mandated reductions in emissions intensity.

6.3 Impacts on the Sectoral Level

Of specific interest for analyzing the sectoral impacts of policies targeting reductions in emissions intensity are the fossil-fuel sectors which produce emissions, and the sectors which are direct substitutes or have high emissions inputs, such as the electricity and energy-intensive

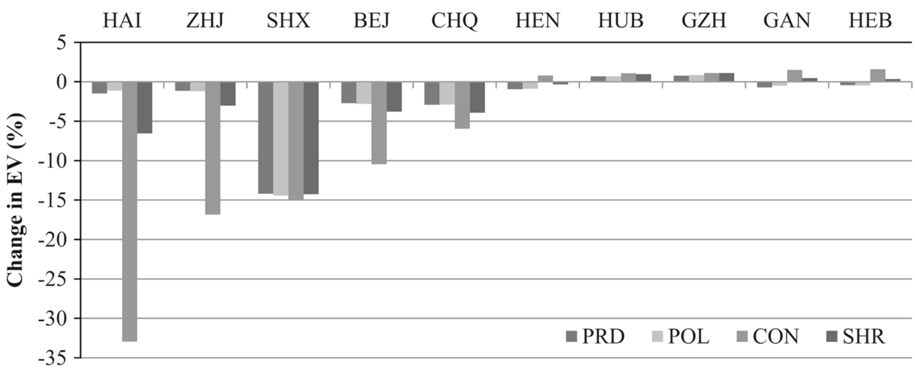

Fig. 4 Changes in equivalent variation of income (EV) for the five provinces burdened most and those burdened least under a consumption-based adjustment of emissions-intensity targets. Regional abbreviations are listed in the caption of Fig. 2

Table 4 Regional changes in output and prices for the coal (COL), electricity (ELE), and energy-intensive (EID) sectors

Sector	Region	Output changes (%)				Price changes (%)			
		PRD	POL	CON	SHR	PRD	POL	CON	SHR
COL	Eastern	−24.46	−25.23	−28.40	−26.53	−8.16	−8.23	−7.84	−8.25
	Central	−11.99	−12.06	−11.38	−12.24	−11.36	−11.39	−11.09	−11.39
	Western	−20.15	−19.40	−16.90	−18.67	−8.76	−8.69	−8.03	−8.52
	China	−16.80	−16.81	−16.50	−17.00	−10.09	−10.10	−9.70	−10.07
ELE	Eastern	−14.91	−16.36	−29.42	−23.73	17.23	18.45	19.78	18.73
	Central	−16.21	−15.32	−2.22	−9.20	15.90	15.58	12.15	13.05
	Western	−13.06	−11.23	−3.90	−8.44	10.20	9.57	7.78	8.58
	China	−14.93	−15.10	−16.90	−16.73	15.50	15.89	14.62	14.88
EID	Eastern	−3.79	−4.50	−10.30	−5.53	2.37	2.52	3.03	2.59
	Central	−3.76	−3.29	4.07	−1.50	3.05	2.99	2.27	2.52
	Western	−7.69	−6.64	0.37	−4.93	3.75	3.55	3.01	3.17
	China	−4.33	−4.49	−5.20	−4.43	2.73	2.78	2.82	2.65

sectors. Table 4 lists the output and price changes in those sectors for the model scenarios considered.

The Chinese primary energy mix is dominated to about 70 % by coal resources (NBS China 2008). Emission-intensity targets induce a substitution away from energy-intensive coal to less energy-intensive energy carriers, such as natural gas and renewable resources. Table 4 indicates that coal production is reduced by about 17 % in each policy scenario. The price for coal reduces due to a drop in demand by about 10 % on aggregate. In accordance with the distribution of emissions-intensity targets, the reductions in coal production are higher in the eastern provinces (24–28 %) than in the central and western ones (11–12 and 17–20 % respectively). This trend is most accentuated in the consumption-based scenario. The western provinces increase their coal production by 3 percentage points (15 %) in the consumption-based scenario relative to the production-based one, while the eastern provinces decrease their production by 4 percentage points (17 %).

The implementation of regional targets for reducing emissions intensity creates an implicit price for emissions inputs. This increases the prices for affected commodities, such as electricity and energy-intensive goods, which reduces output. Table 4 indicates that the price for electricity increases by 15–16 % in each policy scenario on aggregate, inducing a reduction in output of similar percentages (15–17 %). There are big differences across the scenarios on the provincial level. While the percentage output reductions in electricity are relatively evenly distributed in the production-based scenario (13–16 %), the range widens in the other policy scenarios, in particular in the consumption-based one (2–29 %). In the latter the eastern provinces are allocated more stringent emissions-intensity reduction targets. As a result, those provinces seek to substitute domestic electricity generation which would increase their emissions intensity with electricity imports from other provinces. This decreases electricity generation in the eastern provinces (by 15 percentage points compared to the production-based scenario), but increases generation in the central and western provinces (by 14 and 9 percentage points, respectively, compared to the production-based scenario). Similar trends can be observed for energy-intensive goods. Prices increase by about 3 percentage points in each scenario on aggregate and output decreases by 4–5 percentage points. Again, the eastern

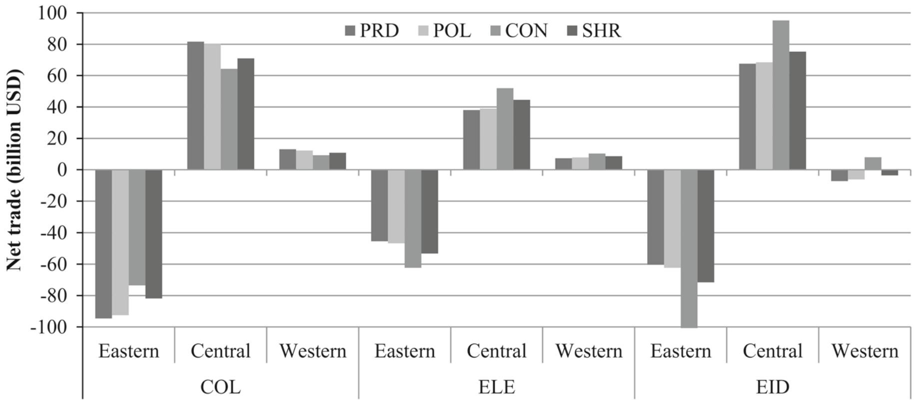

Fig. 5 Regional net trade flows (exports minus imports) in billion USD for the coal (COL), electricity (ELE), and energy-intensive (EID) sectors

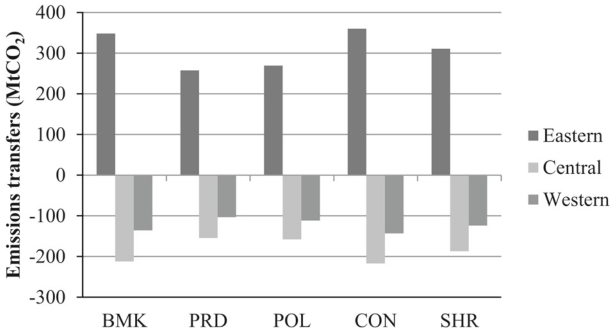

Fig. 6 Emissions transfers (emissions embodied in imports minus emissions embodied in exports) in the policy scenarios considered and the no-policy benchmark (BMK)

provinces exhibit a decrease of energy-intensive production, while the central and western provinces exhibit an increase (of about 8 percentage points each).

Associated with changes in output and prices are changes in trade flows. Figure 5 displays China's interregional net trade flows (i.e., exports minus imports) in billion USD. In line with the output changes discussed above, coal imports by the eastern provinces decrease by 22 % in the consumption-based scenario compared to the production-based scenario. At the same time, the eastern provinces' electricity and energy-intensive imports increase by 37 and 71 % respectively. The corresponding exports of the central and western regions increase by 37 and 41 % for electricity, and by 41 and 209 % for energy-intensive goods. Thus, implementing consumption-based emissions-intensity targets results in significant outsourcing of energy and energy-intensive production from the eastern provinces to the central and western ones.

6.4 Feedback on Emissions Transfers

The outsourcing effect has further repercussions on emissions embodied in trade and interprovincial emissions transfers. Figure 6 displays the interregional emissions transfers resulting from the policy scenarios considered. In the consumption-based scenario, the net emissions transfers outside the eastern provinces increase by about 12MtCO_2 (4 %) compared to the benchmark. The consumption-based approach to regional target allocation therefore creates incentives which perpetuate the imbalance of consumption-based emissions it seeks to address. As a consequence, the regional differences in reduction targets and the economic effects resulting from those, such as sectoral specialization and outsourcing, can be expected to increase with every iteration of target setting.

Figure 6 indicates that all other policy scenarios result in a decrease of emissions transfers from the eastern provinces to the central and western ones. The decreases amount to 26 and 23 % in the production-based and politics-based scenarios respectively, and to 11 % in the shared-responsibility scenario. The latter indicates that the economic and emissions unbalancing effects of the consumption-based approach can be remedied by weighing consumption-based emissions responsibilities with other allocation metrics, such as production-based responsibilities in the shared-responsibility scenario.

7 Discussion and Conclusion

Estimates of emissions embodied in trade and analyses of the distributional and political implications of consumption-based approaches to emissions accounting have been of great interest in the last years. While consumption-based emissions inventories are now regularly constructed for various countries and regions in the world, little attention has been devoted to the possible methods and potential economic effects of implementing consumption-based emissions responsibilities into actual policy making. This study addresses those two points by developing a consistent methodology for adjusting regional emissions-reduction targets for trade-induced emissions transfers and by simulating the economic effects following from their implementation for the context of China's Twelfth FYP and its allocation of emissions-intensity reduction targets among its provinces.

This study finds that in 2007 China's eastern provinces are net importers of emissions embodied in interregional trade, while the central and western provinces are net exporters. The magnitude of interregional emissions transfers from the eastern provinces to the central and western ones amounts to 14 % of the eastern provinces' territorial emissions. Adjusting the regional emissions-intensity reduction targets for those emissions transfers increases the reduction burden for the eastern provinces by about 60 % on aggregate, while alleviating the burden for the central and western provinces by 55 and 49 %, respectively.

Our CGE analysis indicates that this redistribution of reduction burden could double China's national welfare loss compared both to a homogenous allocation of reduction burden under a production-based approach and to the politically-adopted allocation of the Twelfth FYP. The results show that the welfare losses for the eastern provinces increase by a factor of four on aggregate and up to a factor of 22 for individual provinces. The central provinces' welfare losses are only slightly lowered when adopting consumption-based reduction targets, while those of the western provinces increase despite their lowered reduction burden.

The sectoral analysis indicates that the consumption-based allocation of reduction targets results in significant outsourcing of energy and energy-intensive production from the eastern provinces to the central and western ones. This is found to increase the interregional emissions transfers between those regions above benchmark levels. The consumption-based approach to regional target allocation as implemented in this study therefore creates incentives which perpetuate the imbalance of consumption-based emissions. As a consequence, the regional differences in reduction targets and the economic effects resulting from those, such as sectoral specialization and outsourcing, can be expected to increase with each iteration of consumption-based target setting. Those results caution against an approach for allocating emissions-reduction burden based solely on consumption-based emissions responsibilities.

Another caveat of allocating emissions-intensity targets solely by a regional consumption-based approach is the potential interaction with those emissions that are embodied in international (instead of interregional) trade. In 2004, 22.5 % of the emissions produced in China were embodied goods exported to other countries (Davis and Caldeira 2010). Those export goods, in particular labor-intensive textile goods and wearing apparel are primarily produced in the eastern provinces, while a smaller portion of energy-intensive exports is produced in the central and western provinces (Guo et al. 2012). A comprehensive consumption-based adjustment of emissions-intensity targets would need to take into account those international emissions transfers, which may raise conflicts with issues of national sovereignty.

This study has analyzed a shared-responsibility approach to target allocation as a potential remedy for the unbalancing effects of the consumption-based approach. The shared-responsibility approach divides emissions responsibilities between the consumer and the producer. It was found that allocating regional reduction targets by following this approach largely alleviates the negative effects that an allocation that is solely based on the consumption-based approach has on national welfare. In particular, the national welfare loss is reduced to levels comparable with those under a production-based allocation. Welfare losses for the central and western provinces are slightly reduced compared to those of the production-based approach and the high welfare losses that the eastern provinces experience in the consumption-based approach decrease markedly. The outsourcing effects are also alleviated, so that emissions transfers from the eastern provinces to the central and western ones decrease below benchmark levels. The shared-responsibility approach thus demonstrates that integrating consumption-based emissions responsibilities with other allocation metrics, such as producer responsibilities, can constitute a potential option for future emissions-reduction allocations. The analytical part of this study provides the general methodology necessary for deriving a combined index for target allocation.

Another potential policy option for addressing distributional concerns while avoiding the unbalancing effects of a consumption-based approach could be an emissions-trading system. Zhang et al. (2012) have demonstrated, in a computable general-equilibrium framework for the Chinese context, that a national emissions-intensity target, together with emissions trading, reduces national welfare loss relative to implementing regional targets that do not allow for emissions trading. Within an ETS, distributional concerns could potentially be addressed by differentiated baseline allocation. While we defer a detailed analysis of this policy option for future research, we note that the improvements in measuring emissions that will be needed for a future ETS in China (see e.g., Han et al. 2012) are similarly beneficial for enabling the implementation of the different allocation methods analyzed in this study.

Although the numerical results obtained in this study hold strictly only for the specific parameter values and assumptions adopted in our model framework, we have taken steps to ensure the model provides a framework suitable for the policy comparison undertaken in this study. Importantly, our CGE analysis assumes that China's economy is characterized by perfectly competitive markets, something which is easily contestable. Zhang et al. (2012) test the effects of market distortions and parameter assumptions on the results obtained with their regional CGE model for China. They find that subsidized end-use prices for electricity increase regional welfare losses as costs are not passed through. Constraints on capital mobility have been found to lead to effects in the same direction, albeit without changing the direction of relative impacts between a regional target scenario and a national one with trading. Similar results can be expected to hold for this multi-scenario comparison. Nonetheless, additional modeling studies and parameter analyses for the Chinese context, in particular of the elasticities of substitution which can have significant effects on the supply and demand responses (Sue Wing 2004; Jacoby et al. 2006) are highly encouraged.

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Appendix 1: Elasticities of Substitution

Table 5 Reference values of elasticities of substitution in production and consumption

Parameter	Substitution margin	Value
σ_{en}	Energy (excluding electricity)	1
σ_{enoe}	Energy—electricity	0.5
σ_{eva}	Energy/electricity–value-added	0.5
σ_{va}	Capital—labor	1
σ_{klem}	Capital/labor/energy—materials	0
σ_{cog}	Coal/oil—natural gas/fuel gas in ELE	1
σ_{co}	Coal—oil in ELE	0.3
σ_{gf}	Gas—fuel gas in ELE	10
σ_{hr}	Resource—Capital/labor/energy/materials in hydro ELE	1
σ_{nr}	Resource—Capital/labor/energy/materials in nuclear ELE	1
σ_{wr}	Resource—Capital/labor/energy/materials in wind ELE	1
σ_{var}	Resource—Capital—Labor in AGR and OMN	1
σ_{rklm}	Capital/labor/materials—resource in primary energy	0
σ_{ct}	Transportation—Non-transport in private consumption	1
σ_{ec}	Energy—Non-energy in private consumption	0.25
σ_{c}	Non-energy in private consumption	0.25
σ_{ef}	Energy in private consumption	0.4
σ_{l}	Leisure—material consumption	1

Appendix 2: Emissions-intensity targets by Province

Table 6 Emissions-intensity reduction targets (%)

Region	PRD	POL	CON	SHR
ANH	17.4	17.0	16.3	16.9
BEJ	17.4	18.0	85.0	51.2
CHQ	17.4	17.0	33.9	25.6
FUJ	17.4	18.0	40.8	29.1
GAN	17.4	16.0	0.0	8.7
GUD	17.4	20.0	18.4	17.9

Table 6 continued

Region	PRD	POL	CON	SHR
GXI	17.4	16.0	7.1	12.2
GZH	17.4	16.0	0.0	8.7
HAI	17.4	11.0	86.2	51.8
HEB	17.4	18.0	0.0	8.7
HEN	17.4	17.0	6.3	11.9
HLJ	17.4	16.0	13.9	15.7
HUB	17.4	17.0	1.7	9.6
HUN	17.4	17.0	15.1	16.2
JIL	17.4	17.0	11.7	14.5
JSU	17.4	19.0	31.6	24.5
JXI	17.4	17.0	16.2	16.8
LIA	17.4	18.0	7.2	12.3
NMG	17.4	16.0	0.0	8.7
NXA	17.4	16.0	20.2	18.8
QIH	17.4	10.0	0.0	8.7
SHA	17.4	17.0	10.1	13.8
SHD	17.4	18.0	16.5	17.0
SHH	17.4	19.0	14.3	15.9
SHX	17.4	17.0	0.0	8.7
SIC	17.4	18.0	15.6	16.5
TAJ	17.4	19.0	17.2	17.3
XIN	17.4	11.0	11.9	14.7
YUN	17.4	17.0	0.0	8.7
ZHJ	17.4	19.0	90.8	54.1
Eastern	17.4	18.6	27.8	22.6
Central	17.4	16.8	7.9	12.6
Western	17.4	15.7	9.0	13.2
China	17.4	17.4	17.4	17.4

Appendix 3: Economic Impacts by Province

Table 7 Percentage changes in welfare as measured by equivalent variation of income

Region	PRD	POL	CON	SHR
ANH	−1.21	−1.20	−1.19	−1.14
BEJ	−2.72	−2.80	−10.47	−3.79
CHQ	−2.91	−2.88	−5.94	−3.93
FUJ	0.09	0.05	−2.21	−0.68
GAN	−0.72	−0.49	1.51	0.47
GUD	−0.46	−0.60	−0.89	−0.46

Table 7 continued

Region	PRD	POL	CON	SHR
GXI	0.05	0.12	0.14	0.25
GZH	0.79	0.86	1.12	1.10
HAI	−1.49	−1.13	−32.95	−6.55
HEB	−0.43	−0.47	1.60	0.34
HEN	−0.94	−0.88	0.80	−0.32
HLJ	−4.75	−4.54	−4.88	−4.45
HUB	0.68	0.69	1.09	0.96
HUN	−1.52	−1.50	−1.60	−1.41
JIL	−0.85	−0.85	−1.07	−0.74
JSU	−0.33	−0.47	−1.79	−0.90
JXI	−0.90	−0.91	−1.63	−0.95
LIA	−1.52	−1.60	−0.62	−0.96
NMG	−3.81	−3.66	−1.89	−3.00
NXA	−1.96	−1.91	−3.83	−2.27
QIH	−0.46	0.27	0.20	0.31
SHA	−4.23	−4.26	−4.06	−4.09
SHD	−1.58	−1.69	−1.07	−1.45
SHH	0.11	0.04	0.25	0.31
SHX	−14.19	−14.44	−15.03	−14.26
SIC	−1.69	−1.77	−1.86	−1.62
TAJ	−2.36	−2.60	−4.85	−2.54
XIN	−3.94	−3.55	−4.85	−3.91
YUN	0.55	0.57	0.26	0.58
ZHJ	−1.14	−1.20	−16.84	−3.02
Eastern	−0.87	−0.96	−3.64	−1.20
Central	−2.26	−2.23	−1.90	−2.00
Western	−1.50	−1.44	−1.79	−1.43
China	−1.36	−1.39	−2.84	−1.46

Table 8 Percentage changes in GDP

Region	PRD	POL	CON	SHR
ANH	−0.88	−0.87	−0.90	−0.82
BEJ	−0.98	−1.01	−2.81	−1.22
CHQ	−0.96	−0.97	−2.09	−1.25
FUJ	−0.03	−0.04	−0.81	−0.28
GAN	0.23	0.29	0.76	0.50
GUD	−0.29	−0.35	−0.57	−0.29
GXI	−0.28	−0.26	−0.29	−0.21
GZH	0.36	0.42	0.86	0.66

Table 8 continued

Region	PRD	POL	CON	SHR
HAI	−0.82	−0.69	−12.01	−2.76
HEB	−0.15	−0.16	0.43	0.05
HEN	−0.29	−0.26	0.35	−0.08
HLJ	−1.49	−1.47	−1.76	−1.43
HUB	0.14	0.14	0.45	0.34
HUN	−0.93	−0.93	−1.00	−0.86
JIL	−0.57	−0.58	−0.76	−0.52
JSU	−0.24	−0.28	−0.76	−0.42
JXI	−0.57	−0.57	−0.80	−0.56
LIA	−0.43	−0.46	−0.18	−0.26
NMG	−1.40	−1.35	−0.52	−1.08
NXA	−0.93	−0.91	−1.51	−0.99
QIH	1.41	0.71	−0.29	0.59
SHA	−1.79	−1.80	−1.76	−1.74
SHD	−0.29	−0.31	−0.27	−0.25
SHH	−0.16	−0.19	−0.12	−0.07
SHX	−5.36	−5.48	−6.10	−5.59
SIC	−0.86	−0.88	−1.02	−0.83
TAJ	−0.72	−0.78	−1.50	−0.77
XIN	−1.64	−1.51	−1.89	−1.61
YUN	0.01	0.04	0.03	0.10
ZHJ	−0.38	−0.40	−5.30	−0.92
Eastern	−0.32	−0.35	−1.27	−0.43
Central	−1.05	−1.04	−0.92	−0.94
Western	−0.69	−0.69	−0.85	−0.67
China	−0.56	−0.57	−1.12	−0.59

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